UNITED NATIONS ENVIRONMENT PROGRAMME

ENERGY FOR RURAL DEVELOPMENT

A Time to Act

A report to the United Nations Conference on New and Renewable Sources of Energy

Nairobi, 10—21 August 1981

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PREFACE

The 1970s brought into focus the general realization that fossil fuel resources, especially oil and natural gas, are finite in nature and that countries should explore the possibilities of using other sources of energy as well, establishing thereby an appropriate energy "mix" to meet their demands for development. The pressing need to develop alternative sources of energy is most marked in the developing countries, especially in rural areas. It is here that hundreds of millions of people live far from the mainstream of development activities, and in conditions of abject poverty, which cause degradation of the quality of life and hence of the social dimension of the human environment. The provision of an adequate supply of energy to rural areas will not only promote rural development and hence improve the quality of life in such areas, but will also reduce the rural - urban migration that has exacerbated the already dire urban problems.

The Governing Council of the United Nations Environment Programme has fully recognized this problem and at its 3rd session in 1975, requested the Executive Director of UNEP to accord high priority to the establishment in some rural areas of developing countries of a few demonstration (experimental) centres which will harness, individually or in combination, locally available renewable sources of energy. At its 4th session, in 1976, the Governing Council requested the Executive Director to accelerate an active programme involving the rational utilization of renewable resources for energy generation which will have a positive impact on rural development, consistent with environmentally sound practices, and at its 7th session, in 1979, the Executive Director was urged to promote more activities related to the development of renewable sources of energy, energy conservation measures and the development of efficient technologies for the production and use of energy.

The present report summarizes the preliminary results of three experiments undertaken in Sri Lanka, the Philippines and Senegal. In addition, several studies have been initiated to determine the feasibility of harnessing renewable sources of energy in rural areas of Indonesia, Somalia and in the Arab Region. Furthermore, UNEP is according high priority to studies of energy supply/demand and patterns of energy consumption in rural areas and also to increasing the efficiency of energy production and use in such areas.

Essam El-Hinnawi
Chairman, Energy Task Force
United Nations Environment Programme

Nairobi, July, 1981

THE SRI LANKA EXPERIMENT*

* Based on a report prepared by Dr. H. Jack Allison, Policy Analyst in the Science, Technology, and International Affairs Directorate of the US National Science Foundation (formerly Professor of Electrical Engineering, Oklahoma State University), who acted as senior consultant for the UNEP-sponsored project. Additional material was taken from progress reports prepared by Dr. I. Usmani (Senior Energy Adviser to UNEP, now to TCD, United Nations) and by the Ceylon Electricity Board.

Sri Lanka (formerly Ceylon) is a pear shaped island near the southern tip of India. It is approximately 435 kilometres long and 225 kilometres wide, and has a total land area of approximately 65,600 square kilometres. Geographically, its location is between 6° and 10° North Latitude and between 79° and 82° East Longitude. The climate of Sri Lanka is governed by the mountain barrier of its highlands, which are located slightly south and west of the centre of the island. These mountains, some of which are over 2.5 km in elevation, interact with the southwest and northeast monsoons which are characteristic of that part of the Asian subcontinent to produce heavy rainfalls in the mountain areas, and lesser amounts in the coastal lowlands. Average rainfall for the country is approximately 2 m. The combination of heavy rainfall and the abrupt change in elevation from the mountainous area to the coastal lowlands has given Sri Lanka an excellent hydro-power potential.

Sri Lanka :*

Population :	*15 million*
GNP/capita :	*190 US $*
Adult Literacy :	*78%*
Rural Population :	*73% of total population*
Primary Energy Production:	*0.154 million tce (Hydro-power)*
Electricity Production :	*1.35 X 10^9 kWh of which 1.26 X 10^9 kWh hydro, rest thermal*
Commercial Energy Consumption:	*109 kg coal equivalent/capita*
Electricity Consumption :	*91 kWh/capita*

* *All data are for 1978; World Development Report, World Bank, 1980; World Energy Supplies, United Nations, 1979*

The UNEP-sponsored Experimental Rural Energy Centre (REC) in Sri Lanka is located in Pattiyapola village (Fig.1). The project was implemented by the Ceylon Electricity Board, with advice from Oklahoma State University (Professor H. Jack Allison) and Dr. I. Usmani (Senior Energy Adviser to UNEP at that time; now Senior Energy Adviser to TCD, United Nations, New York). Pattiyapola village was selected for the experiment for the following reasons:

1. Proximity to Colombo - driving time is approximately three hours through an extremely scenic part of the island.

2. Contact of the desired continuity from a high government level to the village leadership already exists.

3. Proximity to Hambantota - where extensive meteorological information is available which indicates that the solar and wind resources at the site should be suitable for the REC.

4. Statements of interest from the villagers - the village leaders were most interested in participating in the programme and pledged their co-operation in every way possible.

5. Layout of the village - most of the villages in the southern part of Sri Lanka have developed along the roads linking the larger cities in the area. They are, therefore, spread along several kilometres of roadway and cannot be considered villages in a compact sense. Pattiyapola village lies along a reservoir boundary and is, therefore, more compact than most of the villages considered for the experimental REC.

PATTIYAPOLA VILLAGE :

The total number of households and the population of the village were estimated to be 375 and 2250, respectively. The configuration of the village is such that approximately 70% of the houses are isolated from the remaining 30% by the village "wewa", or reservoir. This offered the possibility that some services might be provided to only a part of the village if economic considerations made such an action necessary.

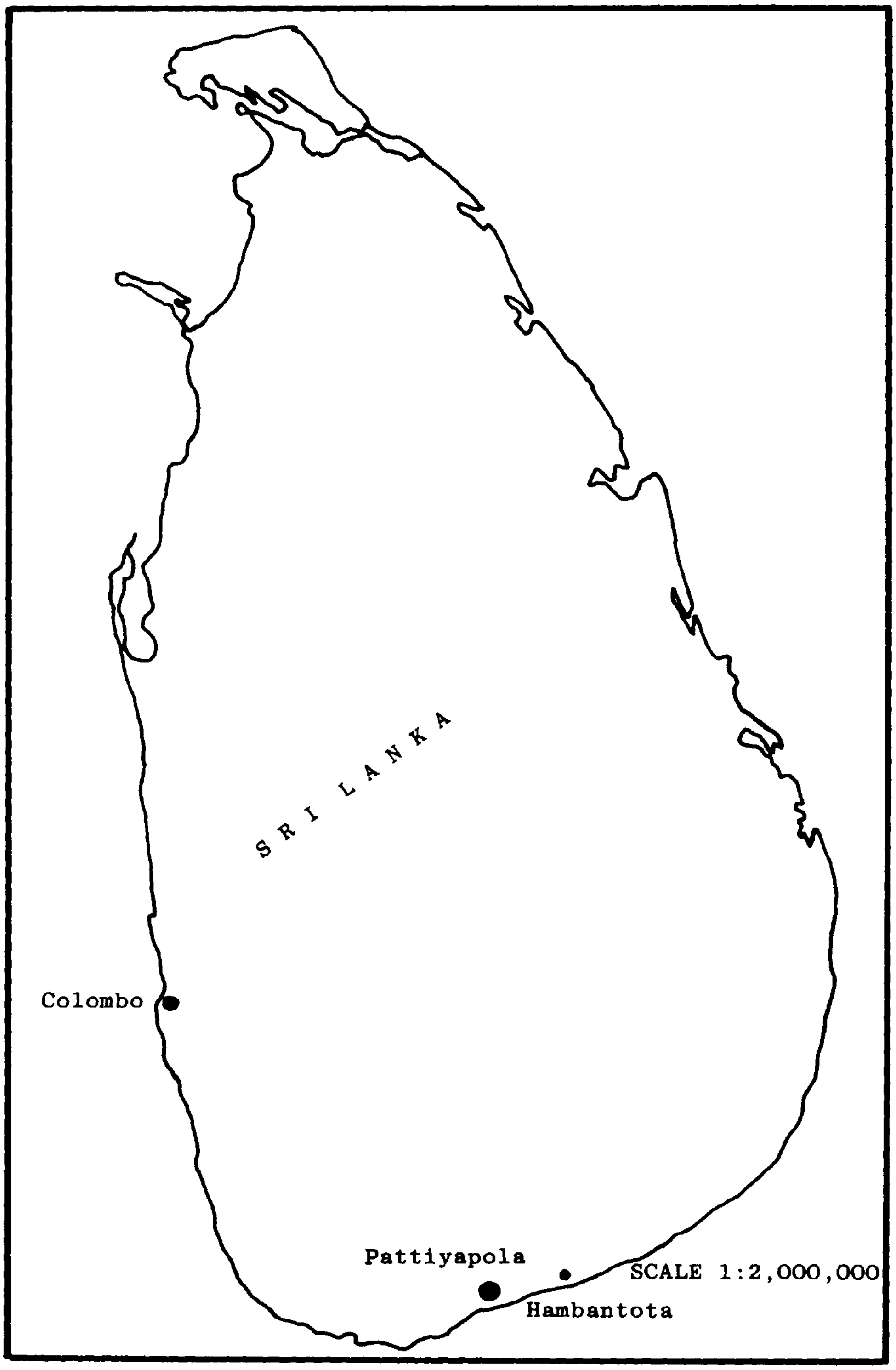

Fig.1. Map Showing Location of Sri Lanka REC

The literacy rate for the population over five years of age was found to be 85%. This figure compares very favourably with the corresponding literacy rate for the entire population of Sri Lanka. The bulk of the population has been educated to the primary level (40%) and to the middle grade (30%), and 9% have passed higher examinations. Such relatively high educational levels were considered crucial to the acceptance of innovative concepts, such as those which might be associated with the Sri Lanka REC.

The total population over five years of age was classified according to their activity categories, and it was observed that 21% were employed, 15% were unemployed, 17% were engaged in household work, 35% were students, and 12% were either retired, disabled, or too young to work. Thus 53% of the village population comprise the labour force and the remaining 47% constitute the economically inactive, or dependent, population.

An analysis of the composition of the labour force indicated that 58% were employed and 42% were unemployed, thus indicating a high degree of non-utilization of the available work force. Even among those employed, the actual participation in activities was shown to be extremely low. It is noteworthy that more than 45% of the total available man days had been lost due to impaired health conditions alone. Malaria was found to be the prime cause of impaired health in the village, and Infective Hepatitis and Typhoid also had a high incidence rate. Low income and productivity, seasonality, and non-availability of suitable job opportunities were also causes and consequences of the under utilization of man power in the village.

Most of the housing units available in the village are single family houses with cadjan roofs and mud walls which can be considered as improvised structures of a semi-permanent nature. More than 65% of the housing units have a floor area less than 46 sq. m. The average floor area per housing unit was 58 sq. m. The average number of rooms for a single housing unit was 4.0, and more than 50% of the units have 2 or 3 rooms. The average number of occupants for a single housing unit was determined to be 5.9.

Most of the villagers obtain their potable water supplies from wells scattered around the village. The wells are the open type which is characteristic of most Asian villages. The probability of intrusion of organic waste material which affects the quality of water from such wells is high. The village experience with the wells has caused the villagers to be suspicious of the water obtained from them. As a health precaution, most of the villagers boil the well water prior to drinking, due to a seasonal variability in the quality of the water. Villagers whose houses are in close proximity to Pattiyapola reservoir depend on tank water for essentially all of their water requirements.

In an average household consisting of 5.9 persons there are about 1.4 income receivers. More than 60% of the households had one income receiver, and the average household income was about Rs. 324/- per month (about 18 US $; the exchange rate taken as 1 US $ = 18 Rupees).

The bulk of the household income is from agricultural produce, which accounted for nearly 60% of the total income. Wages and salaries accounted for only 12% of the total income, while the shares of the non-monetary income amount to 11%, representing the rental value of the owner occupied dwellings. Profits and income from unincorporated enterprises accounted for 17% of the total income. This source of income included profits derived from business activities, manufacturing (bricks, cadjan leaves for thatching, etc.), trade, transport, animal husbandry, and fishing.

In the ownership of land, it was observed that an average household owned or held approximately 5 acres of high land and 1.7 acres of paddy land (one acre is equivalent to .01 hectare). Approximately 45% of the high lands were used for coconut cultivation, and 5% was used in combination with coconut cultivation for growing citronella grass. (Citronella is a fragrant grass that yields an oil used in perfumery and as an insectifuge. The village has a factory for processing the citronella. The energy source for the factory is firewood and citronella grass). Chena cultivation (minor crops) and citronella grass cultivations, respectively, used approximately 16% and 18% of the available land. The remaining 21% was uncultivated. The paddy lands are cultivated only once per year, due to the limited capacity of Pattiyapola reservoir. The average ownership of cattle/buffaloes is approximately 5 heads per household. Most of these animals are allowed to graze freely throughout the village area, and a total animal population in excess of 1000 heads was noted.

All households in the village use firewood for their daily cooking and for boiling of drinking water as a health precaution. Firewood is found in abundance within the village and in the jungle pockets surrounding the village. The leaves, trunk, shells and husks of the coconut palm are burnt extensively as a source of thermal energy. This type of firewood derived from the coconut palm is found in large quantities in the coconut cultivations. The daily requirement of firewood per average household ranges from 12 to 15 kg (the price of firewood in a nearby town is about 4-6 Rs., i.e. about 20-30 US cents per 100 kg). The common device used by the households for burning the firewood is the open fire.

Kerosene oil is used as the source of energy for lighting purposes of the households. Coconut oil is also burnt for lighting purposes but its use has been limited only to the temples and to the places of worship. The device commonly in use for burning the kerosene oil is the combination of cloth wick and the bottle, which is a potential fire hazard especially in rural housing units with cadjan roofs. A few households are in possession of "Petromax" type kerosene oil, pressure lanterns, which is portable and is used extensively as the source of light during threshing of paddy carried out usually in the night. The average requirement of kerosene oil per household per day is about 0.4 to 0.5 litre (the cost of kerosene is about 0.9 Rs. per litre).

RENEWABLE SOURCES OF ENERGY IN PATTIYAPOLA :

A study was undertaken to determine the feasibility of harnessing locally-available renewable sources of energy in Pattiyapola. Special attention was given to the possibilities of harnessing wind power, solar energy and to anaerobic fermentation of organic wastes.

Extensive data was provided which documented the solar and wind characteristics at various meteorological stations around the island. Of particular interest was the data provided for the Hambantota station, which is located a few kilometres west of Pattiyapola village. Figure 2 is a plot of average monthly wind speed at Hambantota versus wind speed for the period of 1911 through 1960. The data show an average wind speed of 12.3 miles per hour (19.8 kilometres per hour) for the 49 year period. Comparable average wind speeds have been found by plotting data for 1967 and 1975. These plots indicate an extremely reliable and strong wind regime for the Hambantota station for over 64 years. The distribution of wind speeds at Hambantota on an average day for each month of the year for 1975 shows that a wind speed in excess of ten miles per hour can be expected to occur for more than half a day for an average day at Hambantota, except for the months of April and November.

Solar energy data for the Hambantota station is presented in Figures 3 and 4. Figure 3 is a plot of average solar intensity per ten hour day, in watts per square foot, versus months for a typical year, 1965 - (one watt per square foot is equivalent to 10.76 watts per square metre). The data show a minimum solar intensity of approximately 44 watts/ft^2 for July, with a maximum solar intensity of approximately 78 watts/ft^2 average for April. Figure 3 indicates that at least 500 watt hours per square foot of land surface can be anticipated in regions of Sri Lanka which are in close proximity to Hambantota on an average day. Figure 4 is a plot of average solar insolation in watts/ft^2 versus hours for an average day in 1965 at Hambantota. Again, an average insolation in excess of 500 watt hours per square foot is noted.

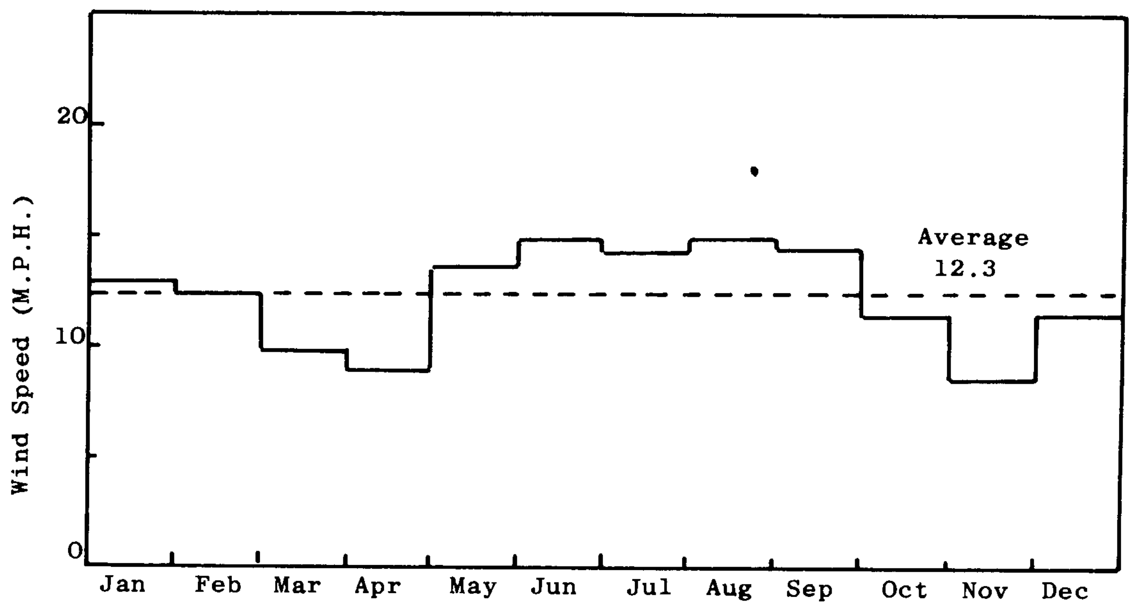

Fig.2. Average Monthly Wind Speed At Hambantota (1911-1960)

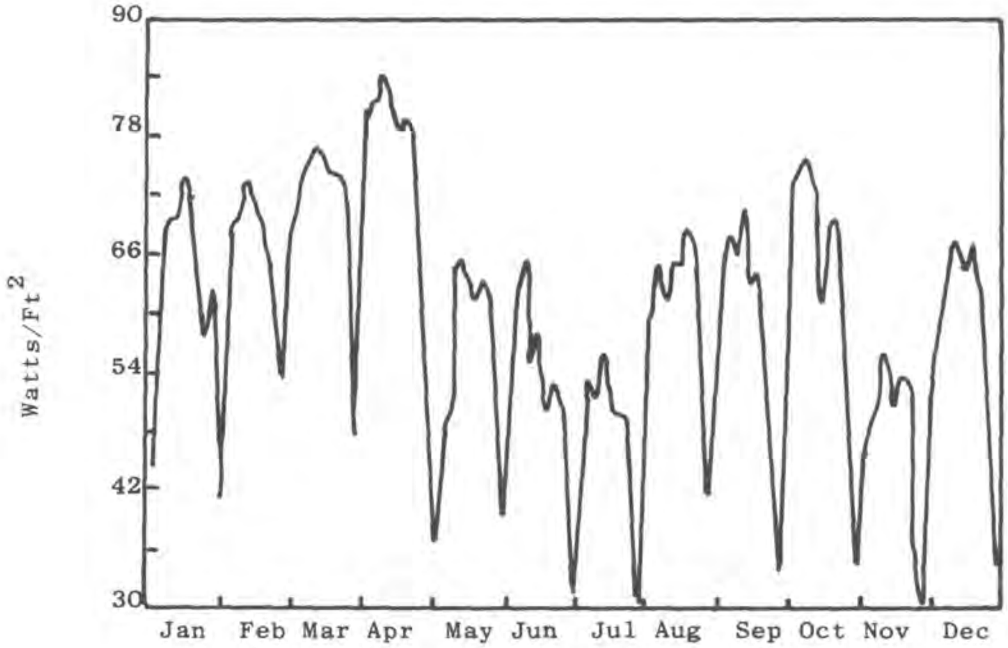

Fig. 3. Average Solar Intensity Per 10 h. Day For Given Month

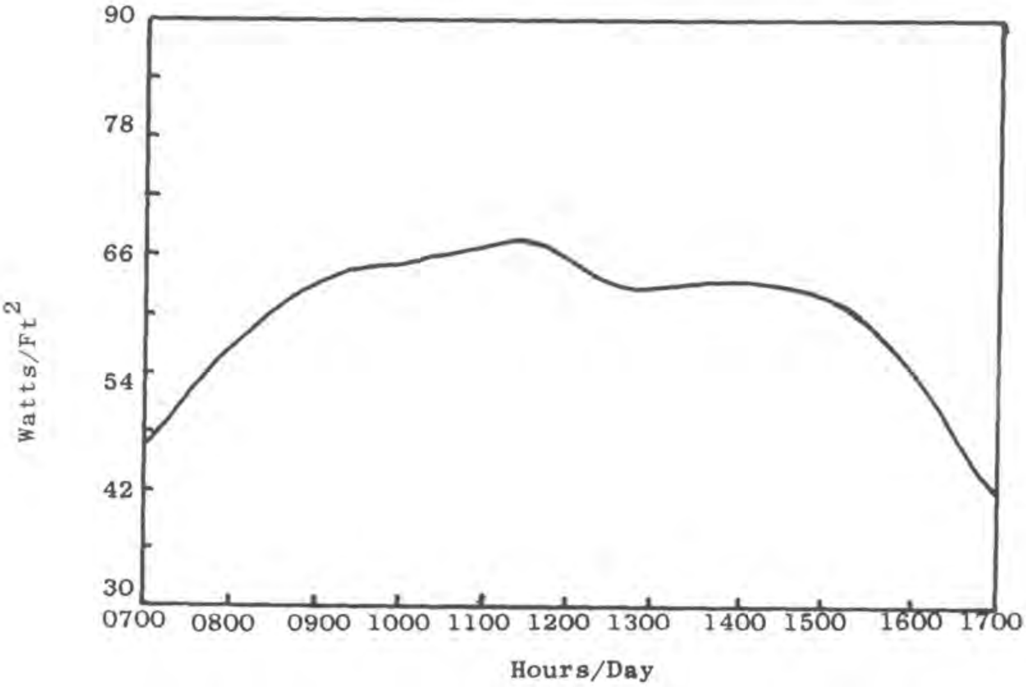

Fig.4. Average Solar Intensity Per 10 h. Day For Given Year (1965)

It must be noted that the Hambantota station is located on the southern coast of Sri Lanka, and that Pattiyapola village is several kilometres inland and approximately 50 kilometres east of the meteorological station. There is, therefore, the possibility that the meteorological information which was accumulated during the data collection phase of this study might not be totally representative of the conditions prevailing at the REC site. There is little doubt that this uncertainty is characteristic of any remote village in a developing country. The problem could be solved by installing a complete, battery powered meteorological station at a promising site, and then accumulate data for several years before documenting the approximate meteorological character of the site. For the Sri Lanka REC, it was decided that a conservative interpretation of the data which was already available should be used in determining the energy resources available at the site.

The solar energy data which has been discussed was derived from a tabular presentation of the mean percentage of sunshine at Hambantota. Such percentages represent fractions of the solar energy associated with the upper atmosphere of the earth, where cloud cover and other atmospheric disturbances do not interfere with solar insolation. The accepted figure for the solar constant, which is an indication of solar insolation in the upper atmosphere, is .135 watts per square centimetre, or 125 watts per square foot. On a clear day, at sea level, with the sun at zenith, only .100 watts per square centimetre, or 93 watts per square foot of solar insolation can be expected. The latter figure was used to obtain the relatively conservative indication of solar insolation presented in Figure 3 and Figure 4.

Since the power available from the wind increases with the cube of wind velocity, estimating the performance of a wind energy system on the basis of average wind velocities will result in a conservative figure for the power which can be derived from such a system. Three methods were used in calculating the number of kilowatt hours of electricity which could be expected from a typical windmill at Hambantota in 1975. Data showing the variations in wind speed for an average day for each month of the year was available. When such variations were considered, a value of 27,562 kilowatt hours per year was obtained. The calculation was repeated, using the monthly average wind velocity, and a value of 21,019 kilowatt hours per year resulted. Finally, the calculations were completed by using the average yearly wind velocity, resulting in a figure of 18,876 kilowatt hours per year. For each case, the equation used was

$$P = (3.95 \times 10^{-6})\, D^2 V^3 E,$$

where P = power in kilowatts, D = windmill diameter in feet, V = wind speed in miles per hour, and E = windmill efficiency. The resulting figure was then converted into kilowatt hours per month, and kilowatt hours per year through the use of standard procedures (see results in Table 1).

Table 1: A Comparison of Three Methods of Predicting the Energy Available from a Windmill

(Hambantota, Sri Lanka, 1975 Wind Data)

$$P = 3.95(10^{-6})\ D^2V^3E$$

$$E = .3 \quad D = 30$$

	kWh per month		
Month	Mode 1	Mode 2	Mode 3
Jan.	1,670.9	1,606.8	1,573.0
Feb.	2,054.9	1,860.3	1,573.0
March	1,309.4	1,090.6	1,573.0
April	664.2	375.8	1,573.0
May	3,974.4	2,848.8	1,573.0
June	4,874.9	3,551.2	1,573.0
July	2,082.8	1,860.3	1,573.0
Aug.	3,929.0	2,750.6	1,573.0
Sept.	4,273.2	2,972.03	1,573.0
Oct.	1,165.6	864.0	1,573.0
Nov.	613.3	423.4	1,573.0
Dec.	950.6	815.0	1,573.0
kWh/y	27,562.0	21,019.0	18,876.0

Mode 1 - Calculated by Percent Distribution of Wind Speed in an Average Day of a Month

Mode 2 - Calculated on Per Month Average Wind Velocity

Mode 3 - Calculated by Yearly Average Wind Velocity (12.7 MPH)

It should be noted that the results based on monthly average wind speeds are always less than the results obtained through the use of actual wind speed distribution data. On average, monthly average wind speed data produced a result approximately 25% less than would actually be obtained at the Hambantota station. Obviously, using the yearly average wind velocity in determining the performance of a windmill would represent an even more conservative approach to the problem of analyzing such data. However, as shown in Table 1, such an approach would not be conservative in estimating the number of kilowatt hours per month which would be available from a windmill. Therefore, it was decided that estimates of the performances of windmills used in the Sri Lanka REC should be based on monthly average wind speed data.

A basic premise associated with the design of the Sri Lanka REC was that the use of both solar and wind energy as inputs to a renewable energy system could provide a more reliable source of power than would be possible if only one of these resources was used in the system design. As shown in Figure 5, the complementary nature of wind and solar energy at Hambantota gives validity to that premise. The plots indicated represent normalized plots of solar and wind energy available at Hambantota for each month of the year.

Three approaches to using biomass resources in the Sri Lanka Energy Centre were considered: pyrolysis, anaerobic digestion, and fermentation. The technique of pyrolysis was determined to be most effective when plant wastes are used as inputs, because it breaks cellulose molecules into smaller molecules under high temperature conditions in the absence of oxygen. The output of a pyrolytic system is flue gas, char, and a crude form of oil. Although the flue gas is highly variable in heat content, depending on the character of the input plant material, it can be used to drive a heat engine for the production of mechanical or electrical power. The char can be fashioned into briquettes which can be used as a cooking fuel. However, Sri Lanka has little history of using charcoal for fuel, and this output of a pyrolytic system was determined to have little value in that country. Fermentation processes are fairly simple, and they can be used to produce a clean burning alcohol fuel. However, the raw material for most fermenters is sugarcane, corn or other plant material normally used for food, and this fact made it desirable that other techniques of biomass utilization should be emphasized in the Sri Lanka REC.

The technique of anaerobic fermentation, in which organic material is converted into biogas by bacterial action, was chosen for use in the Rural Energy Centre. It offers a variety of

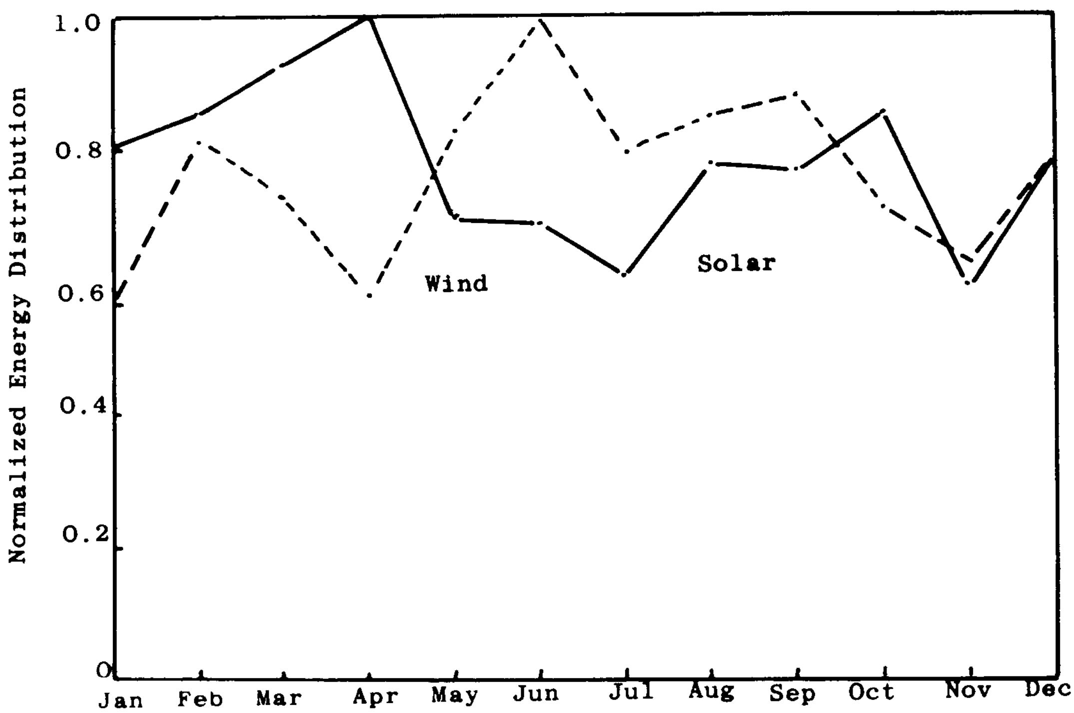

Fig.5. Normalized Plot of Solar and Wind Energy at Hambantota Indicating the Complimentary Nature of These Resources

advantages which make it an important component of the Sri Lanka REC:

1. Biogas units have been developed by developing nations specifically for rural applications.

2. Systems can be fabricated locally, using locally available materials and labour.

3. Biogas can be used directly for cooking or illumination, or used in heat engines to produce mechanical or electrical power.

4. In addition to converting animal wastes into useful energy, biogas generators produce a slurry which can be effectively used as a fertilizer.

5. Improved sanitation can result when human and animal wastes are processed through the system. The bacterial action removes or neutralizes many of the pathogens associated with such wastes.

6. Storage of biogas is an integral component of a biogas digester, and biogas is easily stored under standard temperature and pressure conditions.

7. System operation is labour intensive, and most of the labour requirements are unskilled in nature.

It was determined that Pattiyapola village had sufficient animals to support a digester with a capacity of 85 m^3 per day, and that such a facility would have a sufficient capacity to allow it to be used effectively for a variety of thermal, mechanical, and electrical power requirements (census data indicated the village has in excess of 1000 animals - the waste material from 200 animals is sufficient to operate such a digester at its rated capacity).

THE PATTIYAPOLA ENERGY CENTRE :

For a variety of reasons, past efforts to make use of renewable energy resources to improve the quality of life in rural areas of the developing world have not found wide acceptance. Most were developed for single family applications. This placed a burden of cost and maintenance on individual families, so only the fairly wealthy could afford them. The intermittent nature of most renewable resources made it impossible for them to supply reliable power, thus further decreasing their popularity and usefulness. Many of the devices, particularly solar cookers, required a major adjustment of the life style of the villagers, which many would not accept. Further, most renewable energy systems were developed to serve only one purpose, such as cooking, water pumping, etc., which made them inflexible and unable to satisfy a wide variety of human needs. Finally, a general lack of interest in the local scientific community in such low technology contrivances, coupled with a low level of funding for their development on a large scale, contributed to the general lack of interest in renewable energy systems in most of the developing nations of the world.

The experimental energy system developed in Sri Lanka was designed to minimize the above difficulties. It is unique in that it uses a combination of renewable energy resources to accomplish in a single, integrated system, a variety of applications. Its maintenance and operation are the responsibility of the village, with assistance from the central government. Since the system emphasizes the production of electricity, it represents an alternative to the conventional rural electrification schemes for which funds are allocated in every developing country.

The Sri Lanka Experimental Rural Energy Centre utilizes a multiplicity of renewable energy resources, energy storage mechanisms, and energy conversion schemes to provide energy to Pattiyapola village. Inputs to the system include wind energy, solar radiation and organic wastes. Figure 6 is a schematic diagram of the REC.

Windmill manufacturers throughout the world were contacted in an effort to determine an optimum configuration for use in Sri Lanka REC. Information was received from Australia, Germany, Canada, Switzerland, France, and the United States. The performance of each candidate system was processed from the rating of the manufacturer into a rating which is representative of conditions prevailing at the REC site, using the conservative technique described earlier. A list of windmills which indicates the approximate number of kilowatt hours they can be expected to generate per year at the site is shown in Table 2. It must be noted that the windmills listed in Table 2 are of various configurations and sizes, and that many factors influenced the choice of units which could be recommended for installation in the Sri Lanka REC. Five different manufacturers were initially recommended, primarily because no single unit could be shown to have clear superiority over any other. Maintenance problems for five different windmills made it necessary that only one type of windmill should be used in the REC. The Dunlite 2000, an Australian windmill with a history of successful use in developing countries, was subsequently chosen. Four of these windmills have been installed at the site.

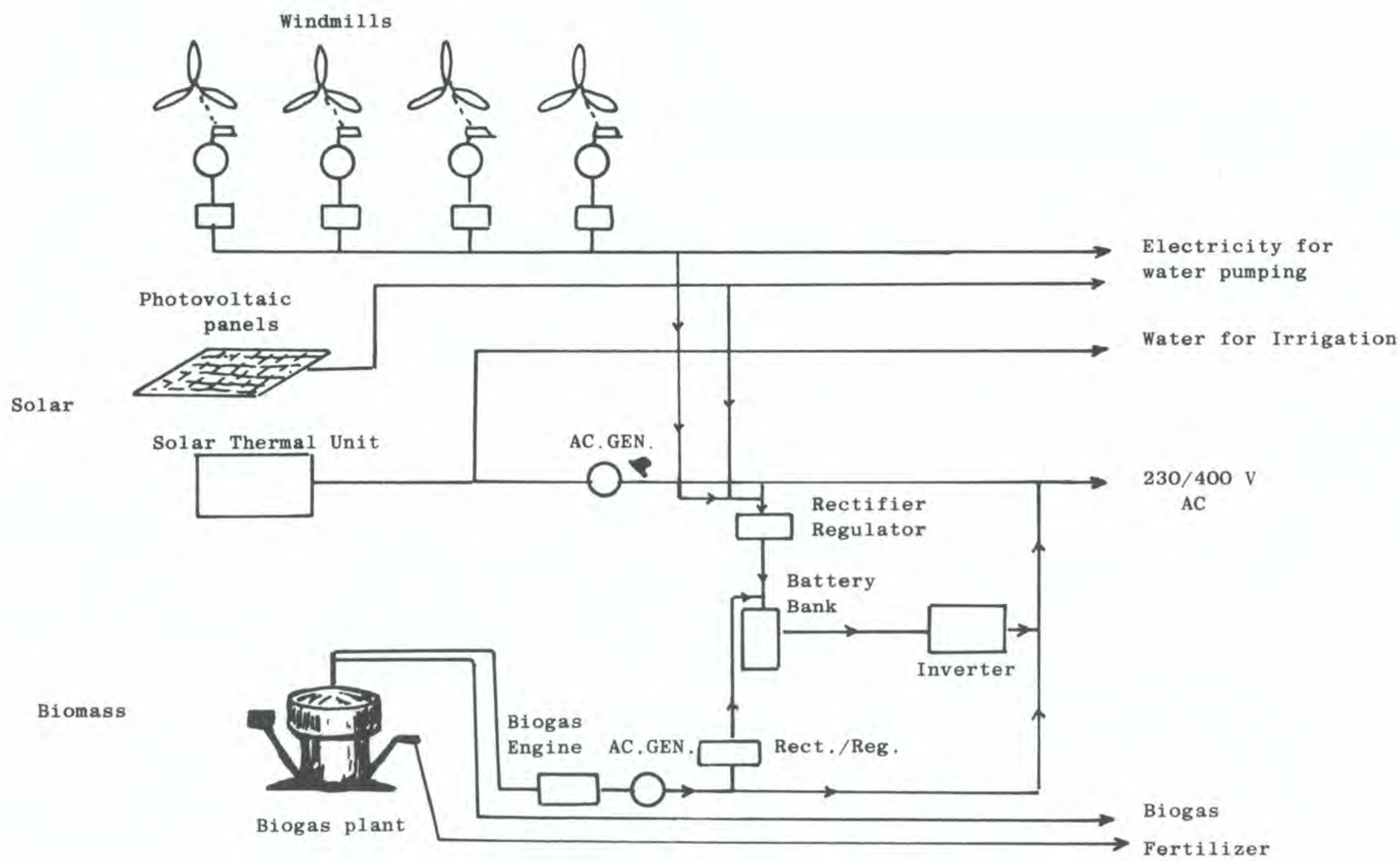

Fig.6. Simplified Schematic Diagram of Sri Lanka Experimental Rural Energy Centre

Table 2: Candidate Windmill Systems

Windmill Type	kWh/year
Dunlite 2000*	3200
D.A.F. 4kW	4300
A.W.T*	4900
Elektro WVG50G*	5300
Aerowatt 1100 FP7	5300
D.A.F. 8kW*	7600
Elektro WVG120G*	9300
Windstream 25*	12000
Aerowatt 4100 FP7	18000

* represents a recommended unit

Three methods of using solar energy in the Sri Lanka REC were considered. The methods were compared on the basis of current and projected economics, technical complexity and sophistication, and proven capability. Systems considered included photovoltaic panels, low and moderate temperature flat plate collectors coupled to a heat engine, and high temperature, concentrating collectors coupled to a heat engine.

Photovoltaic devices provide for the direct conversion of solar energy into electricity. Highly purified silicon, gallium arsenide, or cadmium sulfide materials are used in such cells, and conversion efficiencies in the range of 10% to 20% have been reliably established. Compared to solar thermal systems, photovoltaic systems have the following advantages:

1. No moving parts are required for the production of electricity.

2. Efficient operation without tracking requirements.

3. Basic material, silicon, is widely available in unprocessed form (sand) in most developing countries.

4. Can produce an effective output even when moderate cloud cover is present.

5. Minimal maintenance problems.

6. Costs for photovoltaic systems are dropping rapidly, promising economic viability in this decade.

Comparative disadvantages of photovoltaic devices include the following:

1. High technology required for fabrication and assembly.

2. Present costs are higher than competing techniques for directly harnessing solar insolation.

3. Power conditioning is required to optimally interface cell output with load.

In 1976, when the basic characteristics of the Sri Lanka REC were identified, photovoltaic panels cost approximately $25.00 US per peak watt. When final design decisions were made in 1978, this cost had dropped to approximately $10.00 per peak watt. This drop is consistent with predictions made by many authorities that the price of such cells will drop to 50 US cents per peak watt before the end of this decade. If such projections approach reality, then photovoltaic conversion systems will revolutionize energy systems in both the developing and the developed nations of the world.

These considerations made it desirable to use a photovoltaic system as one of the components of the Sri Lanka REC, and a photovoltaic panel with a rating of 2000 W (peak) has been installed at the site (supplied by Solar Power Corporation, U.S.A.).

Solar energy systems which use solar heat to produce mechanical or electrical power have two basic components: a configuration which collects solar radiation and converts it into heat, and an engine which converts that energy into mechanical or electrical power. Solar collectors were found to have an increasing cost and degree of sophistication with increasing operational temperature. Engines which convert relatively low grade heat energy into mechanical power were found to have an efficiency which increases dramatically with increasing boiler temperature. The selection of the solar thermal component of the Sri Lanka REC was based on a compromise between system sophistication and efficiency. High temperature solar thermal systems were found to have the following advantages over low, or moderate temperature systems:

1. High efficiency, approaching 30% in some systems.

2. High temperatures make possible the use of conventional steam engines for the production of mechanical power.

3. Subject to extensive research and development in many countries.

4. Can produce potable water as a by-product of the thermal reaction.

5. More effective use of land area for energy production.

Corresponding disadvantages were considered, including the following:

1. Relatively new and sophisticated technology.

2. Limited operational experiences - units are still in the experimental stage of development.

3. High cost.

4. Systems must track the sun. Diffuse solar insolation does not contribute significantly to system performance.

Omnium-G, a California based US manufacturer, was selected to be the supplier of the solar thermal system for use in the Sri Lanka REC. Although their system must be considered to be in an experimental stage of development, it has been extensively studied by the Solar Energy Research Institute (SERI) in the United States, and many countries, including India, Pakistan, Australia, and Saudi Arabia have acquired Omnium-G units for study.*

The biogas plant installed at Pattiyapola produces 85 m^3 of biogas per day and was designed and built by the Khadi and Village Industries Commission, Bombay. The plant is mainly fed with cow

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* The solar thermal unit (7.5 kW) failed to operate at Pattiyapola. The system is being redesigned by the Jet Propulsion Laboratory under instructions from the U.S. Department of Energy because in addition to Sri Lanka, countries like India, Italy, Libya and others who had purchased this unit, have found its design defective. At present, the REC at Pattiyapola operates without the solar thermal unit.

dung (about 2400 kg per day - provided by 300 cattle). The biogas is mainly injected into a spark ignition generator and a diesel engine to produce electricity. A 37.5 KVA engine generator, modified to operate on biogas, was supplied by Onan, U.S.A.; and a 12.5 KVA diesel engine generator was acquired locally by the Ceylon Electricity Board and modified to operate on a blend of biogas and diesel fuel.

The Sri Lanka REC was designed to supply reliable power to Pattiyapola village, using only intermittent and renewable resources as inputs. Energy storage is a fundamental component of such a system. Techniques of energy storage which involve superconduction, flywheels, compressed air, hydrogen, or advanced batteries are currently under development by research groups throughout the world. At the present time, however, none of these techniques have reached the point of development where they can be considered for use in the REC. It was determined that energy storage through the use of commercially available batteries represented the only technique which could be considered.

The choice of a battery storage system for use in Sri Lanka was based on several constraints, including cost, maintenance requirements, cycle efficiency, and cell lifetime. It was determined that lead acid batteries were most suited for the desired application. The most common lead acid battery is the lead-antimony system which has been in use for many years. It has a relatively long lifetime, and is inexpensive. The C & D Batteries Division of Eltra Corporation, USA., supplied the battery storage component of the REC; the batteries selected are the combined lead antimony type used by NASA in its energy storage studies. Sixty large cells are connected in series to give the DC storage system a normal rating of 125 V. A 50 kW static inverter, supplied by International Power Machines Corporation, U.S.A., is used to convert the output of the storage system into 50 HZ, 230/400 volts AC which is compatible with the standard electrical distribution system in Sri Lanka.

The basic structure of the Sri Lanka REC can now be described. Windmills are used to generate electricity and pump water. The solar energy system producing electricity will act as a compliment to the wind energy component. The electrical output of the solar and wind energy systems are connected to a storage system whose output is available when the wind and solar energy resources cannot be used directly. Since a storage system is used to buffer the input and output energy rates associated with the solar and wind energy components of the REC, some method of inversion has been required to produce alternating current from the direct current stored in the system. The size of the storage system would be prohibitive if only solar and wind energy inputs were used in the system. Since biogas furnishes an additional input to the system, it is used as an additional storage component for the system, as a back up when the solar and wind energy inputs are unavailable and when the battery storage unit is depleted.

The Experimental REC at Pattiyapola has a generating capacity of about 70,000 kWh per year (4 windmills: 12,800 kWh/y; biogas system: 40,000 kWh/y; solar system: about 17,000 kWh/y). However, the energy which will actually be available for use will be less than this figure, because of the losses associated with charging and discharging the main battery bank of the system, DC motor/AC generator conversion, and distribution. The efficiency of these components is estimated as 80%, 70% and 90%, respectively, and the product efficiency of these losses is about 50%. Therefore, the total energy available from the system can be estimated to be about 35,000 kWh/y, assuming that all of the energy generated passes through the storage system (the battery bank).

On an experimental basis, the electricity produced from the REC will be used for household lighting, street lighting and for provision of drinking water. According to the Ceylon Electricity Board, each household is to be provided with a maximum of 4 electrical outlets and the lamps shall be of 40, 40, 25 and 25 W rating (fluorescent lamps may be used). Thus the quantum of energy required annually for the lighting of 100 households with 4 hours of use per day will be 18,980 kWh. A total of 24 street lighting fixtures have been considered at main road junctions on the "Wewa" reservoir and at several other intermediate locations. Another 6 lighting fixtures have also been considered within the REC premises. The quantum of energy required annually for these street lamps at the rate of 80 W per lamp and 12 hours of use per day will be 10,512 kWh/y. Water for domestic purposes (mainly for drinking) will be pumped to a water treatment plant, where it will be made available to the public. The energy requirements for the provision of water for 100 households, each consisting of 6 persons, have been estimated at 1947 kWh/y. In summary, the energy required for the provision of lighting and domestic water supply for 100 households and for street lighting is 31,439 kWh per year.

In other words, the REC at Pattiyapola should provide electricity for the needs of 100 households (a part of the village) and for street lighting in that sector of the village. At present 40 households have been connected to the system and street lighting fixtures have been installed. The average monthly consumption of the 40 households has been found to be about 600 kWh. The sludge produced as a by-product from the anaerobic fermentation of organic wastes in the biogas plant is being used - on an experimental basis - as a fertilizer in a village rice paddy.

ECONOMIC CONSIDERATIONS AND EVALUATION :

Since the Sri Lanka Experimental Rural Energy Centre has only been recently commissioned (the system is operational without the solar thermal unit which will be installed after the necessary changes in its design are made), it is premature to give here a final evaluation (economic, operational, social or environmental) of this experiment.

However, it should be pointed out that the Sri Lanka Experiment is unique. It represents the first effort to harness renewable energy resources in a decentralized, integrated system which can supply reliable power to a rural area. Attempts to document the economics associated with such an effort should consider many factors, including the following:

1. The Experiment is designed to serve as a catalyst to stimulate interest in harnessing renewable sources of energy.

2. The REC provides, in one facility, a sample of the broad spectrum of technological systems which can harness renewable energy resources for the benefit of a rural village in a developing country.

3. It can be used as a training centre for developing local expertise in handling a broad spectrum of renewable energy technologies.

4. It can be used as a testing facility for advanced technology transferred to a developing country (in this case Sri Lanka), and for the evaluation of the acceptability of such technologies.

5. The Centre was designed to supply a variety of services to Pattiyapola village. These services include reliable electrical power, potable water, fertilizer, and a reduction in the health hazards associated with untreated animal wastes.

It is apparent that the first four factors listed above could have been implemented with an institute, or laboratory, with no effort to make use of the output of the system in a real village setting. This possibility was considered in the preliminary discussions which led to the development of the REC. It was concluded that such an approach would represent a sterile, analytical approach to a human problem, and that the essential character of a Rural Energy Centre could best be demonstrated and tested in an actual village setting.

It is recognized that the electrical output of the Sri Lanka REC will be competitive with more conventional schemes of rural electrification only if it can be shown to have performance characteristics and cost figures which can be competitive with such systems. At present, conventional methods of supplying electricity to remote villages involve either an extension of existing electric grids or the use of autogeneration devices such as diesel generators. The latter is generally excluded as a means of rural electrification in developing countries because of uncertain fuel supplied (and the rapidly escalating prices of fuel). The availability and cost of diesel fuel has limited the application of autogeneration systems to special requirements in rural areas, such as hospitals or tourist accommodations in the past. Unless biogass systems are developed to supply fuel for autogeneration (a feature of the REC), it is highly unlikely that autogeneration will have a significant role in the future.

Although the Sri Lanka REC does not suffer from the problems encountered with conventional approaches to supplying energy to rural areas in developing countries, sufficient uncertainties remain regarding its character to prevent a definitive analysis of the economics associated with the Centre at this time. In addition to the multple purposes and outputs of the REC which have been described, the following system characteristics require further quantification:

1. Some components of the REC are still in an experimental stage of development (e.g. the solar thermal unit). Estimates of performance, maintenance, and system lifetime can be quantified only after a sufficient operational data is accumulated and analyzed.

2. None of the system components have benefitted from the cost reductions which can be expected to occur when systems are mass produced.

3. The REC eliminates the need for fossil fuels. This advantage, however, is affected by the higher initial cost of the system. These factors are affected by funding availability (and interest rates).

4. The REC design reflects a balance between energy conversion and storage systems. Both are limited. If the energy generated is not used, it is lost (diesel fuel can always be conveniently stored for later use).

Depending on the values assigned for the above variables, the economics associated with the Sri Lanka REC can be made to appear encouraging or discouraging.

The Sri Lanka Experiment could represent a step toward large scale applications of renewable energy systems. Many of the techniques which have been developed to harness the energy of the sun and the wind offer the promise of significant cost reductions when they are implemented on a large scale. If successful, the REC could result in a large market for this new technology. Further, new techniques of energy conversion and storage can be expected to become part of this, and other, energy centres as they develop. It is possible that their development can be accelerated as the demand for improved systems increases. Of fundamental importance, however, is the fact that renewable energy systems can offer hope for a better life for millions of people in the developing world who are presently unable to benefit from the advantages offered by twentieth century technology.

A PROJECT IN THE PHILIPPINES*

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* Based on progress reports by the Ministry of Human Settlements, Manila which is implementing the UNEP-sponsored project.

The Philippines is more than 85% dependent on crude oil for its commercial energy requirements. This year, the total commercial energy consumption in the Philippines is estimated to reach 20.4 million tonne coal equivalent (tce), of which oil constitutes about 85% (7.5% from domestic sources and 77.5% imported oil). The remaining 15% consist of indigenous coal, geothermal, hydro-electric and non-conventional sources of energy. The total commercial energy consumption in the Philippines is expected to reach about 27.9 million tce by 1985.

*The Philippines**

Population : 46 million

GNP/Capita : 510 US $

Adult literacy : 87%

Rural Population : 64% of total population

Primary Energy Production : 0.881 million tce (coal, hydro, geothermal)

Electricity Production : 16.98 X 10^9 kWh

Commercial Energy Consumption : 339 kg coal equivalent/capita

Electricity Consumption : 366 kWh/capita

* *All data are for 1978; World Development Report, World Bank, 1980; World Energy Supplies, United Nations, 1979.*

The Philippines has recently developed national energy programmes aimed at reducing the dependence on imported oil and maximizing the development of indigenous energy resources. The energy policy strategy of the Philippines focuses on the following issues:*

1. Accelerated diversification to alternative energy resources and the consequent reduction of dependence on oil as the primary source of energy while continuing efforts to discover and produce indigenous petroleum.

2. The accelerated development of indigenously abundant energy resources and a concomitant shift from depletable to renewable resources.

3. Application of non-conventional resources for isolated consumption areas.

4. Development of more efficient technologies for production and use of energy.

5. Adoption of conservation measures.

6. Emphasis on adaptive energy research and development and demonstration programmes towards assimilation of appropriate technologies.

Although some work was carried out in a number of institutions in the Philippines to develop locally-available renewable sources of energy, it was not until the mid-1970s that the potential of such resources has been realized. The promulgation of Presidential Decree 1068 on January 12, 1977 which directed the acceleration of research, development and use of non-conventional energy resources, gave the impetus to maximize the potential from these resources. Since its inception in 1977, the Non-conventional Energy Programme has

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* For details, see : Five-year Energy Programme 1981-1985 and Ten-year Energy Programme 1980-1989, Ministry of Energy, Makati, Metro Manila, The Philippines.

administered a total of 68 projects, with 18 already completed, 27 still in the works, and 23 others in the initiation phase. Broadly, the non-conventional projects may be divided into large- and small-scale categories. Large-scale technologies are those that have the highest potential for substituting for or supplementing highly consumed conventional fuels, such as oil and electricity, and could have industrial application in the near term. Small-scale technologies are those that have uses ranging from household utilization to village electrification and will find their place mostly in rural markets due to availability of resources and site-specificity of the technologies.

The UNEP-sponsored project in the Philippines started in 1978 and is aimed at harnessing locally-available renewable sources of energy in some remote areas of the Philippines, with the target of promoting rural development and improving the quality of life in such areas. The project is being implemented by the Ministry of Human Settlements in co-operation with other agencies and institutions. Emphasis has been made in the project on using indigenous technologies and local skills and on public participation. The latter is a principal component of the "Bagong Lipunan Sites and Services" Project (BLISS), launched by the Ministry of Human Settlements in 1979 to raise the socio-economic conditions of the depressed areas in the Philippines. With every BLISS site, the concept of "Bagong Lipunan Community Association (BLCA)" was introduced to achieve self-reliance among the BLISS residents.

SITES SELECTED AND ENERGY SYSTEMS

Higantangan Island:

Higantangan is an island about five kilometres off the northermost tip of the mainland of Leyte Province, and 14.8 km west from the municipality of Naval in the island sub-province of Biliran where it belongs in terms of political jurisdiction (Fig.7). The island can be reached by water transportation via Naval; Naval is accessible by road from Tacloban which is about one hour by air from Manila. The island has a total land area of 385 hectares. Its topography is gently rolling with a maximum elevation of 48 m above sea level. Coastal areas are generally flat except for the northern and northwestern sections which are rocky and featuring cliff heads from 10-20 m high. The vegetative cover of Higantangan Island generally consists of bushes and low forest on the northwestern quadrant.

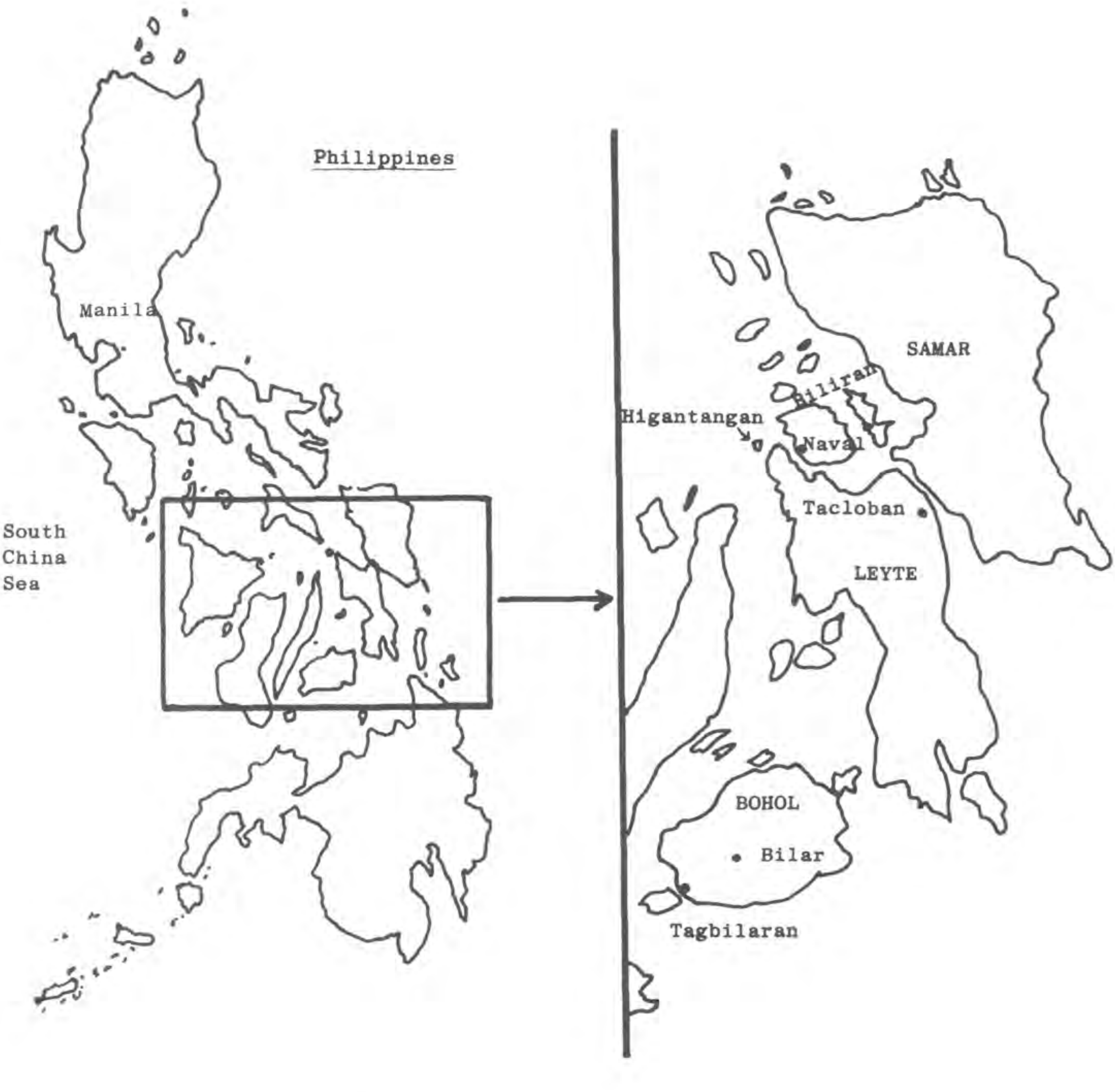

Fig.7. Locations of UNEP-sponsored Project in the Philippines

Coconut plantations are concentrated along the coastal area with some portions planted to root crops.

The island has two barangays (villages): Mabini and Libertad, both located at the eastern side. Both barangays are connected to each other by a kilometre-long road. The island has a total population of 1,600, most are farmers/ fishermen. Some farmers own and cultivate their farms, but a great majority are tenants. The major crop in the island is coconut. Corn, cassava, peanuts, camote and mongo are also raised. Of the agricultural produce, only coconut and mongo are sold to market outlets outside the island mainly at Naval. The rest are traded within the island. Fishing is generally of the sustenance level. Of the total number of fishermen in the island, only 23% are engaged in commercial fishing. Among the various sources of income, mat weaving has the biggest share. About 37% of the households in the two barangays are raising backyard livestock/poultry, such as chicken, cattle, and hogs. These are raised either for consumption, sale or for breeding purposes.

There are 235 dwellings in Higantangan Island. Of these, 55% are situated in Barangay Mabini while the rest are located in Barangay Libertad. Around 15% of the total number of houses are made of wood and cement, with galvanized iron roofings, and 40% are made of wood and nipa roofings. The rest are made of bamboo with nipa roofing material.

All households are dependent on kerosene for their lighting needs. The lighting facilities used are wick lamp and pressure lantern. There is a small electric generator in the island, owned by one family and is used during special occasions only. Wood is used for cooking by about 96% of the household; 3% make use of liquified petroleum gas (LPG) and 1% use kerosene.

About 80% of the residents obtain their potable drinking water supply from two privately-owned water pumps situated in Barangay Libertad. About 12% reportedly draw water from open wells and rain water, 5% from artesian wells and 3% get their water from Naval. There are 20 open wells in the island but the water is salty and is used mainly for washing clothes and dishes.

Preliminary investigations in Higantangan Island revealed that the most urgent need has been the provision of potable water to the residents of the two Barangays. It was, therefore, decided to undertake a detailed study of the groundwater resources of the Island and to study the feasibility of using windmills to pump water. In addition, a family-size biogas plant was included in the project, for demonstration purposes, to encourage the residents to build their own plants and use the biogas for cooking and the sludge, produced as a byproduct of the fermentation process, as a fertilizer.

The domestic water requirements have been estimated at 50 litres per day per capita; the total requirements of the 1,600 inhabitants of the Island would be about 80,000 litres per day. Of these, the two privately-owned wells supply about 20,000 litres. To provide for the balance (60,000 litres), it was found necessary to drill four new wells, two in each Barangay, and to use four windmills to pump the water from the wells into two storage tanks, each with a capacity of about 30,000 litres (Fig.8). Water would then be transmitted by pipes and distributed through suitably located outlets in the two Barangays.

The average wind speed at Higantangan Island has been estimated to be about 16 km/h. Such wind speed is suitable for a low-speed, high torque, multi-bladed windmill. Four of these windmills were supplied by Reymill steel Products, Sta Rosa, Nueva Ecija; a local company that manufacture such windmills.

The windmill has the following specifications :

Number of blades	:	24
Windwheel diameter	:	3 m
Tower height	:	15 m

The pump that the windmill drives is of drop-cylinder type and with a brass-lined, 7.6 cm diameter chamber to resist corrosion. For a stroke of about 18 cm, the pump has a rated capacity of about 25,000 litres per day. The windmill is made of all-steel materials and designed to withstand stresses and torque action induced by excessive wind forces of storms and typhoons and also to resist corrosion. With an average wind speed of 16 km/h, water should be drawn from each well at an average rate of 8 litres/minute. In other words, each tank (receiving water from two wells) should be nearly filled-up every 24 hours.

A biogas plant (based on the Chinese Model) has been built at the Higantangan Community High School for demonstration (and educational) purposes and to provide energy for the cooking needs of the Home Economics Department of the school. The plant produces about 1.5 m^3 of biogas daily.

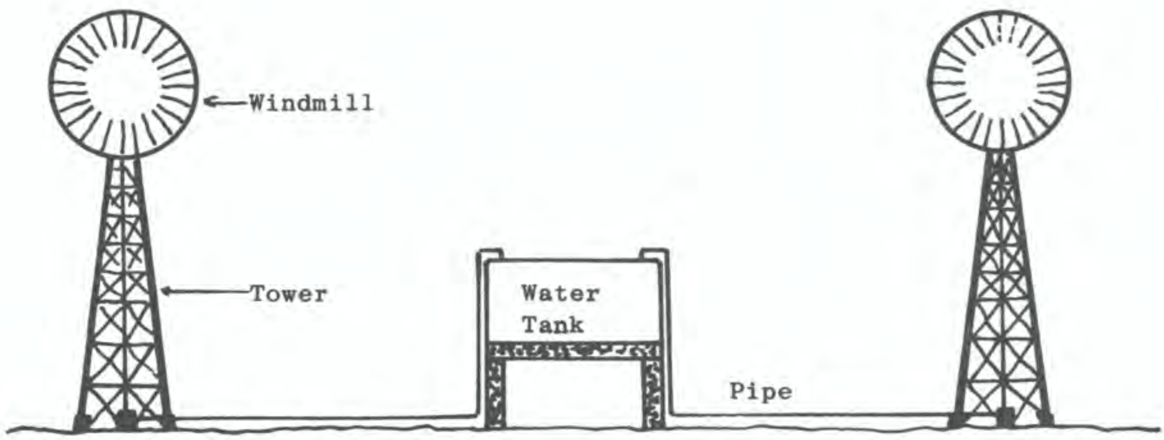

Fig. 8. Windmills connected to Water Tank

The installation and operation of the Wind-Powered Water Supply System in the Island of Higantangan is expected to benefit the two concerned communities in many ways. By harnessing the energy of the wind, the project would practically solve one of the major problems of the island, that is lack of sufficient domestic water supply. With a ready and adequate supply of water, livestock development will be given impetus not only because of the potential earnings that it could generate but also its utility in community-wide biogas operations.

Concomitant projects includes the putting up of a biogas plant with a production capacity of 1.5 m^3 of gas per day for demonstration purposes. Likewise, integral to the whole project is tree planting which intends to promote the culture of such fast-growing species as the ipil-ipil and mangrove plants. Under the tree planting project, the leaves and seeds of ipil-ipil trees can be utilized for animal feed. The wood can be directly used either as cooking fuel or for fuelling a small thermal electric generating plant.

Dagohoy, Bohol:

Barangay Dogohoy is a small village about 7 km from Bilar, a town in the Island of Bohol (Fig.7). Bilar is about 42 km from Tagbilaran which could be reached by air from Manila, with a connecting trip from Cebu.

Barangay Dagohoy has 179 households with a total population of 1,036. About 72% of the households are engaged in cottage industries, while the rest are either employed or engaged in trading or servicing. The households of Dagohoy mainly use kerosene for lighting and fuelwood collected locally for cooking. Preliminary investigations in the Barangay showed that the most urgent need of the population has been the provision of electricity for lighting and for developing the cottage industry in the village. The electricity requirements of the whole community have been estimated as follows :

Households lighting (night time)	9 kW
Cottage industry (day time)	8 kW
Appliances (day and night)	8 kW
Total (anytime)	17 kW

Since Dagohoy is close to Bilar river, studies in the area showed that the volumetric flow and head of Bilar river in the vicinity of Mag-Aso Falls are suitable to allow for the installation of a mini-hydro power scheme at the site. The characteristics of the Bilar river at the site have been found to be :

Effective head	2.44 m
Volumetric flow	3.74 m^3/s
Water velocity	0.34 m/s
Percent utilization of flow	37.5%
Theoretical power output	33.8 kW
Net power output	20 kW (assuming 60% efficiency of turbine and generator)

A low head mini-hydro electric power plant (manufactured in the Philippines) has been installed at the Mag-Aso Falls. It operates on a net head of 2.4 m and a water volumetric flow of 1.41 m^3/s. Of the gross power that can be tapped from the falls about 20 kW is being produced. At certain times of the year, particularly during the dry season of February to May, the volumetric flow of Mag-Aso Falls is considerably lower than during rainy days. This situation is further aggravated by the practice of the farmers in the area who utilize portions of the Bilar River upstream for irrigation purposes during the January-February period. These farmers divert the normal flow of water at various points upstream. However, these situations do not pose a serious technical problem to the project. Damming as originally planned for the project was changed for it would only flood and submerge the small rice farms upstream. The alternative has been to divert a portion of the riverflow via a channel to the power house.

The Mini-Hydro Project is expected to create long range development potential in the area (Figs. 9, 10, 11). By providing power to drive a rice and corn mill, the mini-hydro installation will be servicing a vital need of the population in the area. It will also provide power for small machineries and other types of equipments that would open various opportunities for the seasonally inactive farm workers to engage in various types of cottage, home, and other small-scale industries to further boost their income and thereby attain economic self-sufficiency.

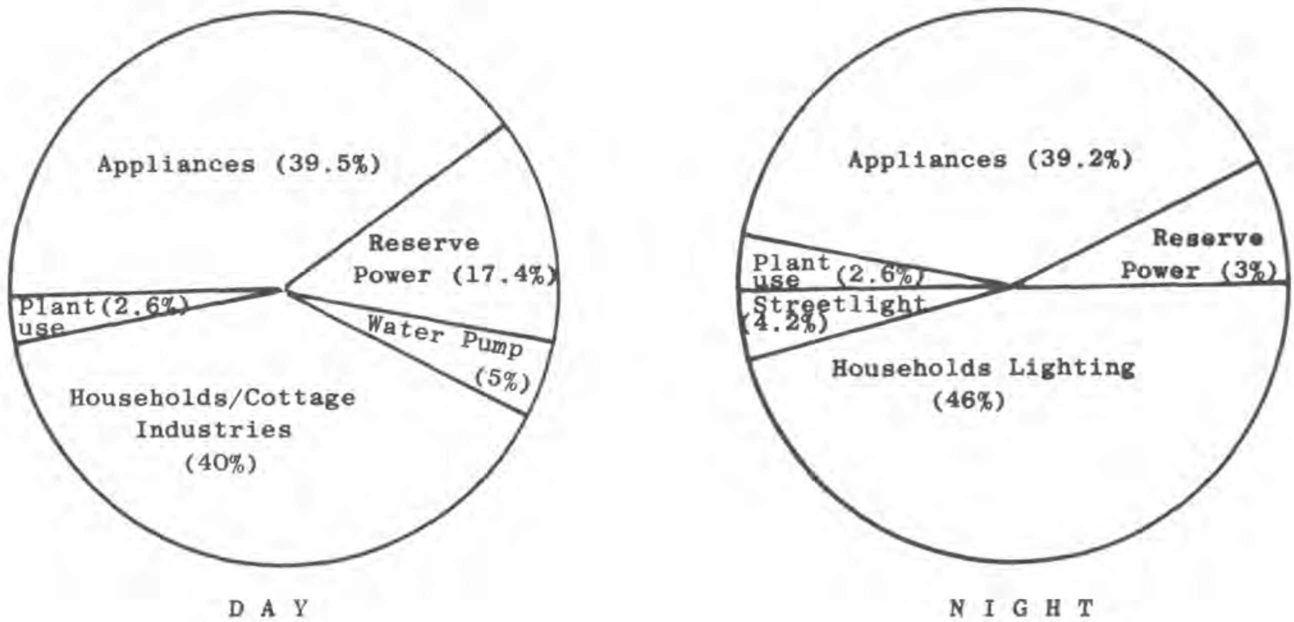

Fig.9. Proposed 20kW Mini-Hydroelectric Plant at Dagohoy, Bilar, Power Load Distribution Scheme

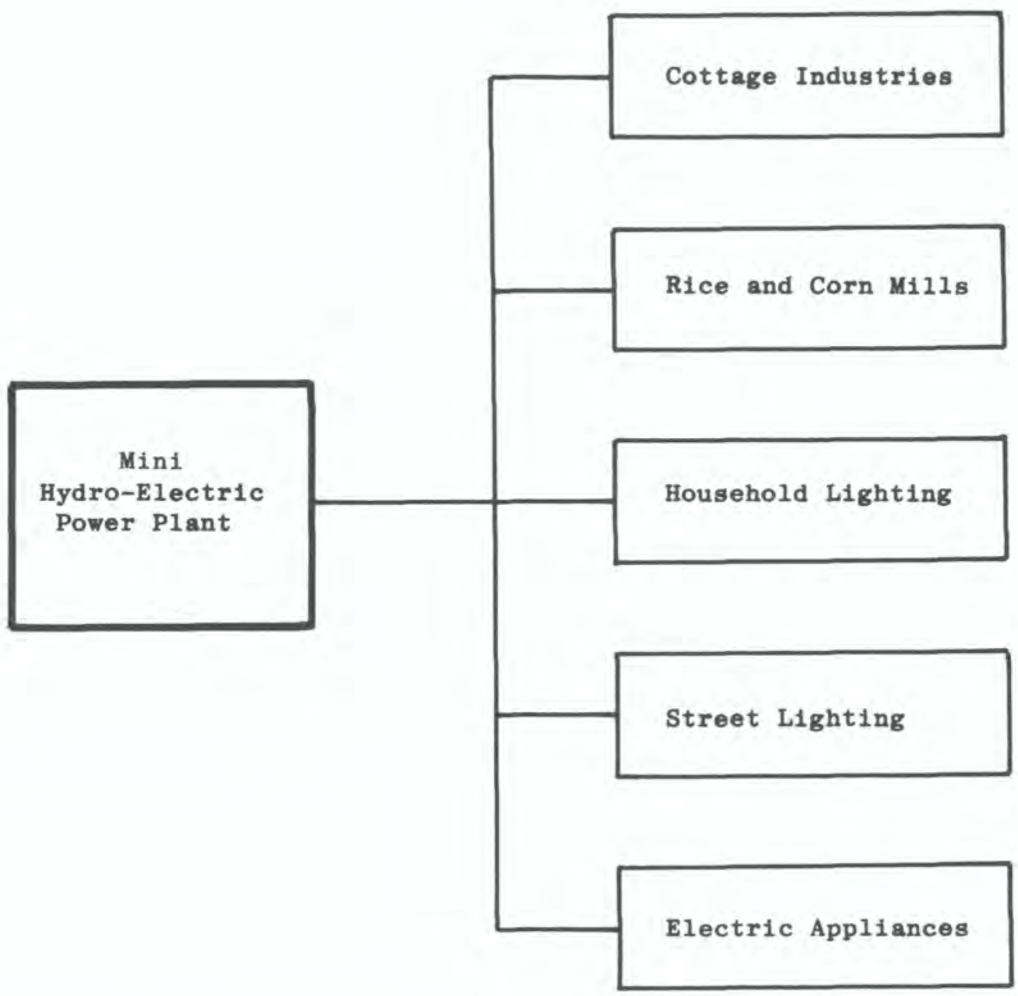

Fig.10. Immediate Applications of Electricity From the Mini-Hydroelectric Power Plant

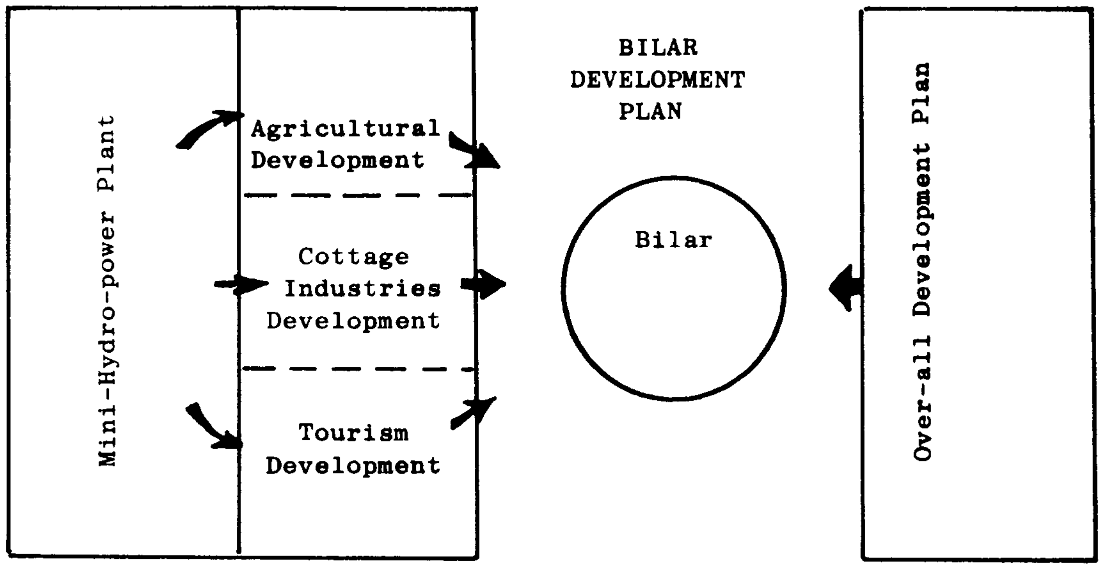

Fig.11 Long-Range Development of Bilar

EXPERIMENTAL RURAL ENERGY CENTRE
IN SENEGAL

Several studies have been undertaken in Senegal to harness locally-available renewable sources of energy. The village of Niagawolof , about 35 km northeast of Dakar, has been selected as the site of the UNEP-sponsored Experimental Rural Energy Centre. Located in an arid zone with a generally hot and dry climate, Niagawolof has a population of about 1,500 living in 140 households. The village economy is primarily agricultural based on the production of vegetables and fruits which are marketed mainly in Dakar.

The main energy sources used in the village are kerosene and fuelwood. Kerosene is primarily used for lighting at the rate of 1,200 litres per month for the entire village. Fuelwood is mainly used for cooking, and it has been estimated that the village uses about 68 tonnes of fuelwood per month.

Preliminary studies in the village showed that organic wastes, solar radiation and wind power are abundant and could be harnessed to provide the village with a part of its energy needs. A biogas plant with a capacity of about 15 m^3/day will be constructed for demonstration purposes and will produce biogas sufficient for meeting the cooking needs of 10 households. The biogas plant will require waste from some 50 animals which can easily be collected in the village(the village has about 1,000 cows, 7,000 sheep and 50 goats).

As the solar insolation in Niagawolof is high , with an average of about 5.5 kWh/m^2/day, photovoltaic panels with a total capacity of 5 kW (peak) will be installed to produce electricity which will be stored in a battery bank for use at night and on cloudy days. The power generated by the panels would be used for pumping water (for drinking and irrigation). Water for drinking will be stored in an overhead tank 5 m high from which water would flow to a central point in the village for use by the community. The volume of water to be pumped will provide water for drinking and other household purposes at the rate of 20 litre/day/person. In addition, electric light will be provided to 100 households, to 10 street lights and to a community medical refrigerator and educational TV set.

Wind energy will be also used to produce electric power at Niagawolof. A wind machine in the 20-40 kW rated capacity will be installed energizing an electric power pumping set that could feed water into a reservoir from which water could be used for irrigation. A suitable plot could be established near the REC to demonstrate the irrigation system the year around. Extra power from the windmill could be used to charge the battery bank.

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