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SOLAR ENERGY - CAPE VERDE

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FOREWORD

This report was written during the term of the technical services work performed for the United States Agency for International Development (U.S.A.I.D.) by the author in Cape Verde from April 1 to September 5, 1983. The work was done for the Cape Verde Renewable Energy Project (625-0937.03) by Development Services Associates under contract no. 625-0937.03-C-OC-3090-00.

The units of money used in this report are the Cape Verdean escudo and the U.S. dollar. Since both use the notation $ they will be defined here as CVE and USD respectively in order to avoid confusion. The exchange rate for these two currencies is usually taken in this report as 70 CVE = 1 USD. However, it has changed over the years as shown in Figure 3 of Section V and occasionally an exchange rate is used appropriate to a certain year.

The report consists in part of papers written separately, then later included in the report. Therefore, numbering of figures, tables, equations and references appears for each section separately. Refer to the end of each section for the references or, ocasionally for the figure captions.

SUMMARY

Three major energy needs, which are especially amenable to satisfaction by solar and conservation techniques, are identified for major attention.
They are:

- Provision of water by pumping and desalination,
- Provision of electrical energy,
- Conservation of cooking fuels.

The primary energy source which is considered is solar energy utilized directly. In order to make cost comparisons and discuss integrated systems, wind and petroleum based energies are also considered. The cooking fuels considered are wood, brush, and agricultural residues. Insolation data is collected, analysed and presented so as to be useful to designers of solar powered systems.

Five technologies or machines for converting the energy sources into the useful products electricity, water and cooked foods are considered. They are:

- Wind machines
- Salt gradient solar ponds,
- Improved cooking stoves and methods,
- Petroleum fueled engines,
- Photovoltaic electricity generators.

Technical and cost evaluations of some combinations of these energy needs, energy sources, and connecting technologies are presented for development.
They are:

- Desalinated water - electrical power production systems powered by combinations of petroleum sources, wind machines and solar ponds,
- More efficient cooking methods and devices,
- Isolated rural electrical power for small water pumping, refrigeration, lighting, communications.

Programs to accomplish this are suggested and outlined. They are programs recommended for immediate implementation and long range implementation.

The programs for immediate implementation are:

- Planning for and design of desalination-electricity production systems using a combination of petroleum, wind and salt gradient solar ponds. This includes planning for a rejuvenated salt production industry.
- Construction and operation of a solar pond for developing an in-country capability,
- Development and diffusion of more efficient cooking methods and equipment.

The programs for long range implementation are:

- Establishment of an insolation measurement program.
- Development of a capability in photovoltaic power generation.
- Construction of a solar pond of approximately 65,000 square meters to furnish power to the Sal Island desalination-electricity generation system.

As examples, a model solar pond development project (Appendix D) and a model project for improved cooking technologies (Appendix E) are presented.

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I. INTRODUCTION

The objective of this study is to determine if solar energies can reasonably contribute to satisfaction of some energy needs in Cape Verde and to suggest developmental projects for promising cases. The criteria applied are:

(1) Is there a substantial need?
(2) Is there a substantial energy resource?
(3) Is there a good technology or machine that can economically apply the resource to satisfaction of the need?

Cases for which all three of these questions can be answered positively are analyzed for technical feasibility and cost-effectiveness.

Major energy needs which are clearly identifiable are energies needed for electricity production (commercial, residential, industrial, government uses), water production, transportation, agricultural production, and cooking. Energy needs for domestic and industrial hot water, and building heating and cooling apparently are not large and therefore are not considered in this study.

The solar energy resource is substantial. In this study we arbitrarily exclude the solar derived energies from biomass (except for cooking), O.T.E.C., ocean waves and most fossil fuels. However, it is necessary to consider wind energy and petroleum because these are the competition and we must usually make cost comparisons with them.

Solar energy conversion technologies provide heat, mechanical or electrical energy but, with the exception of biomass derived fuels which are excluded from our study, they are not technically well adaptable to mobile applications. Therefore a large part of the agricultural and all of the transportation energy needs fall by the wayside as far as this study is concerned.

Some cases which easily survive application of all three criteria are water production by pumping and desalination and electricity production for urban and isolated rural uses. In this study we consider them in some detail with respect to solar, wind and petroleum energy sources and conversion technologies.

These three criteria do not appear to be applicable to conservation and more efficient use of energy since there is apparently no source of energy whose size can be determined. However, that is only superficially true since it has been shown that conservation and better efficiency are in reality large energy "sources" (a penny saved is a penny earned). It appears to be the largest energy "source" discovered in the United States during the past decade. Improved cooking methods fall in this category. The need is large. The cost and labor of obtaining cooking fuels are large, land is being over-taxed by excessive fuel

collection including the roots of plants, and the government is incurring substantial expense in its program of butane subsidization. Early results of programs to improve cooking efficiency in other countries look promising so we will assume good technologies for increased efficiency can be introduced. This will also be considered in this study.

This report first makes a brief survey of energy needs. Then the solar energy resource is analyzed. The available insolation data is presented so as to be useful to a designer of solar systems. The wind resource is then reviewed and electric power production by wind machines in Cape Verde is briefly analyzed. The time evolution of the prices of petroleum products in Cape Verde is presented. They have been increasing rapidly in recent years. Then some solar technologies (also wind and petroleum) are applied to the desalination, water pumping and electricity production problems. Finally a few project recommendations are made and a model project for solar pond development is presented.

II. ENERGY NEEDS

No attempt will be made here to make an exhaustive statement of energy needs in Cape Verde. Indeed it would not be possible for some sectors because the basic data does not exist. For example, quantities of different types of cooking fuels used are not known and it would require a fairly serious survey to determine them. Instead, we will list energy needs; then later in this report elaborate on a few which are known to be important and which have good prospects of being satisfied by renewable energy resources and technologies.

1. Energy for mobile applications: This includes transportation and mobile agricultural work. It generally requires liquid fuels although in the past gasification of solid fuels has been used for mobile power. Since biomass resources from which liquid fuels (ethanol, methanol, vegetable oils,...) can be manufactured, are scarce in Cape Verde production of such fuels from internal biomass sources does not appear to be promising.

2. Building heating; domestic and industrial hot water: In northerly climates there are prime prospects for solar heat. However, building heat is seldom needed here and only a few opportunities for solar hot water exist. Solar hot water could be installed at the Praia hospital, at the higher priced hotels and in a few residences. However, for average houses and hotels it is simply not needed. Industrial enterprises that could use solar hot water include the tuna canning factories such as the one in Praia. However, conservation measures (insulating hot water tanks, for example) would probably be more cost-effective. Furthermore, the plant operates only seasonally so that the solar system would not be used continuously (renewable energy systems are not generally cost-effective if there is too much idle time). However, if a new tuna processing plant were to be built it would be appropriate to employ conservation measures and perhaps to install a solar hot water heating system. Even though there are limited opportunities, solar hot water heater should be installed wherever there is substantial, continued use of hot water.

3. Building air-conditioning: There is not a strong requirement for air-conditioning in Cape Verde. The little that is needed could be provided, at lower expenditure for imported fuels, by (1) use of conservation measures (awnings, good maintenance of air-conditioners, weatherstripping, etc.) and by providing renewable, supplementary sources of electric energy for the cities (wind, solar).

4. Electricity:

(a) Rural: Electricity in rural areas can be used to refrigerate (medicines, food products), to illuminate, to pump water, etc. Rural dispensaries in some African countries, e.g., Lesotho, have found solar photovoltaic electric generators to be quite attractive, functionally

and economically, for refrigeration of medicines and for two-way radio communication. Many of the rural dispensaries in Cape Verde are located in towns which have electricity and telephones so this need doesn't appear to be as great. However, small electricity producing units, either wind or solar photovoltaic, may find a place in rural areas and this possibility should be kept in mind.

(b) Urban: Electricity for urban regions is an established need which is currently being supplied by diesel generators and one or two units fired with fuel oil (Mindelo, including the desalination plant). The increasing cost of petroleum imports implies that alternatives to petroleum be tried. Two of the more promising alternatives are wind (which is being started by a U.N. project which will install two 55 kW generators at Praia) and solar electric generation systems. These are discussed in more detail in subsequent sections.

5. Cooking and distilling: Cooking is now done with traditional fuels (brush, wood, dung, agricultural residues) and with butane or kerosene. Grog distilleries use large amounts of agricultural residues, apparently all sugar cane bagasse. We have not determined the quantities of various fuels used annually for cooking and grog making. This would require a through survey and study.

Currently it costs 700-800 escudos to import a bottle containing 12 1/2 kg of butane. It is sold for 600 escudos, the cost of this subsidy being borne by the government. In order to reduce butane costs a project is underway to import in bulk and do the bottling in Mindelo. The cost of firewood in Mindelo was reported to be 4 escudos per kilogram.

A kilojoule of wood energy is therefore 5 times less expensive than a kilojoule of butane energy. Evidently the efficiency and convenience of butane compensate for this cost difference.

The problem of cooking fuels is not only one of expense and labor for gathering but also one of land quality. Gathering of fuel contributes to nearly total clearing of the land including pulling roots. Leaving some of this on the land would reduce erosion and add organic matter to the soil.

6. Water supply: This appears to be the major problem of Cape Verde. Even the food supply could be said to be secondary because it depends on the water supply. Rainfall provides enough water for a short growing season and serves to replenish the underground acquifers.

Secondary supplies of water come from (a) fresh water acquifers (b) brackish acquifers and (c) sea water. The water is obtained from the acqui-

fers by natural flow (springs), by drilling wells and pumping, or by constructing galleries (nearly horizontal tunnels into acquifers which underlie elevated ground, mountains, etc.).

Except for natural springs, energy is required to obtain and/or treat this water. Construction of wells, galleries, and water distribution and storage systems requires energy. Pumping from wells and through distribution systems requires energy. Finally, desalination of saline and sea water requires large quantities of energy. With the exception of perhaps no more than 100 wind powered water pumps and one photovoltaic water pump, all of this energy is supplied by petroleum or human labor. In a later section we shall investigate other sources of energy that can substitute for these.

7. Energy for agriculture: Higher productivity requires higher energy inputs. For food production these energy inputs are (1) land preparation, planting, tilling, harvesting, etc., (2) irrigation (3) insecticides, fungicides, etc. (5) transport and (6) post harvest treatments (threshing, grinding, storage, drying, etc.). We have already discussed (1) and (5) under "mobile applications" and see no easy substitute for petroleum based fuels. The same may be said for (3) and (4) which are manufactured or processed in a foreign country using petroleum fuels and imported, thus adding indirectly to the imported petroleum bill*. Number (2) irrigation has been covered under "water supply". The last group (6), post harvest treatment, permits easier entry of renewable energies. Solar drying of fruits or fish (if agriculture can be taken to include all food production) or of other products is possible. However, solar fish drying in Senegal has a long record of going nowhere. Grain grinding has been done with wind and solar photovoltaic power. Such non-mobile agricultural applications are most suitable for renewable energies.

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* There are, of course, locally produced fertilizers such as agricultural wastes and dung, but much of that is used as fuel for cooking and distilling.

III. MEASUREMENTS AND ANALYSIS OF SOLAR RADIATION IN CAPE VERDE

In order to design solar energy systems and devices and to calculate their performance and costs, one must have rather complete and often detailed knowledge of the solar radiation resource. Specifically, the insolation, both global and diffuse, as a function of time is needed. For some applications the time interval must be 10 or 15 minutes, for others an hour, a day, a month, or even a year.

Insolation data was measured for Mindelo and Praia for many years during the 1950's through early 1970's and recorded in the Anuário Climatológico de Portugal. Recently, measurements have been recommended by AGRHYMET and INIT.

We have collected data from these sources, including from Lisbon and Sal Island, assembled it, analyzed it and presented it in a form that is intended to be useful to the solar designer. However, the data is incomplete in that the time interval is a month, except for Mindelo and a few recent measurements, and the diffuse insolation was not measured. Furthermore, the Robitzsch actinograph used for all the measurements before 1975 is basically not an accurate instrument so that most of the data is not of high accuracy (perhaps 10 % or less).

Therefore, an insolation measurement program should be set up and we have recommended one in later sections of this report.

The reader is referred to Appendix A. for the insolation data and analysis.

IV. WIND ENERGY RESOURCE IN CAPE VERDE

Wind has long been recognized as a significant source of energy in Cape Verde and there is a history of windmill use. Therefore, it is not surprising that a considerable amount of information on the wind resource exists.

1. Sources and Analyses of Wind Data

Wind speed and direction measurements made prior to independence (1975) are contained in the Anuário Climatológico de Portugal [1]. This includes relatively complete monthly data for Mindelo, Sal, and Praia and less complete data for some other stations such as S. Jorge (Santiago) and Monte Velha (Fogo). Furthermore, for Mindelo the Anuário contains daily data, for 3 times of the day, plus the daily average wind speed (wind "run" divided by 24 hours).

In the years after independence wind measurements were made at Mindelo, Sal and Praia. Apparently the best continuous data available is for the Praia airport. The Praia airport data for 1975-1981 was analyzed and presented in an excellent report by Pieterse [2]. This report is the most thorough and useful report on wind energy in Cape Verde to date. It is based on data from an unobstructed anemometer at a height of six meters above the ground at the Praia airport for the years 1975-1981.

The data for Sal island for 1978 is presented and used by Wood [3] in his evaluation of wind energy potential for Sal island. The anemometer was at a height of 8 meters above the ground. Beurskens [4] presents and uses the Praia airport data in his report on the use of wind for water pumping in Cape Verde. Van Meel [5] uses the Praia data in his work on water pumping. Blake [6] presents and analyses the wind data from Praia airport for 1978 in his study of wind power for Cape Verde. The National Climate Center in the USA [7] has reduced Cape Verdean wind to a computer format for Mindelo, Praia and Sal (as reported by Blake [6]. Frandsen [8] uses wind speed data from Sal and Praia in his study of electricity production from wind in Cape Verde and Lambert [9] lists wind data and evaluates wind energy potential for various Cape Verdean locations.

Currently, I.N.I.T. (Instituto Nacional de Investigação Tecnológica) is measuring windspeeds at two higher elevation locations near Praia in preparation for installation of two 55 kW wind turbines which will feed power into the Praia electric power system. Ponta d'Agua is on a ridge which appears to be oriented properly with respect to the prevailing wind direction. Sample data from November, 1982 shows daytime average windspeeds higher than those at Praia airport. The wind speeds at the other site being tested, Palmarejo, appear to be slightly lower than those at Ponta d'Agua.

The AGRHYMET* system of weather stations is effecting wind speed measurements. However, being devoted to agricultural purposes, the measurements are made near ground level, and often near obstructions to wind flow and irregular terrain features. Therefore, these measurements will usually be of marginal use in wind energy work.

2. Characteristics of the Wind Regime

The characteristics of the wind regime in Cape Verde are well described in the works cited above and these should be consulted. A brief summary is given here.

Average wind speed

On Sal island the average wind speeds go from a high of nearly 8.5 m/s in March, April and May to a low of about 6 m/s from July to October [3]. At the Praia airport the high is about 8 m/s and the low is about 5 m/s during these same months [2, 6]. The diurnal variation is characterized by a broad peak from about 100 hours to 1800 hours for

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* AGRiculture, HYdrometry, METeorology measurement network for the Sahel with headquarters in Niamey.

both Sal and Praia [3, 2]. During the "windy" months the average wind speed in the afternoon is nearly 10 m/s in Praia [3]. The early morning hours are the most calm. This diurnal variation is not quite in synchronism with electric power demand which peaks at about 2000 hours in Praia [6].

On more mountainous islands the average wind speed would be expected to be strongly dependent on location. This is borne out by the recent I.N.I.T. measurements on the ridge at Ponta d'Agua. However, very little good data on geographical dependence of wind speeds is available.

Wind speed distribution

Pieterse [2] has found that the Weibull probability density function [10].

$$P(V) = \frac{k}{c} \left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right] \qquad (1)$$

describe the wind regime at Praia airport for the six years 1975-1981. P(V) gives the probability of wind speed, V. The constant c is related to the average wind velocity (see Eq.3) and k is the "Weibull shape parameter".

The shape parameter varies from 2.24 in September to 3.67 in May [2]. This high value of k means that wind speeds are grouped closely about the average speed. This is in sharp contrast to most wind regimes in more northerly climates. For example, in Denmark values of k between 1 and 2 are common [12]; at the Altamont pass wind area in the U.S.A. values close to 1 occur [11]; and the Weibull function may not even represent the data in many cases. The significance of a k value of 3 is that wind systems can be designed which do not have to account as much for very high or very low speed winds.

In Figure 1, we show the measured wind speed distribution for the month of February as given by Pieterse [2]. The Weibull shape parameter, k, is 3.6 and the average speed is 7.89 m/s. In Figure 2, we show the measured annual wind speed distribution for a site in the Altamont Pass east of San Francisco, California. U.S.A. The average speed at this site is 7.4 m/s. If one were to ignore the shoulder on the distribution at 15 to 30 MPH (miles/hour) a Weibull function with a shape parameter near or slightly less than unity would fit the data.

In Figure 3 a series of plots of the Weibull function is shown for shape parameters from k = 3.0, which is close to the Praia data of Figure 1, to k = 1.01 which is similar to the Altamont Pass data of Figure 2 if the bump in the center were removed.

Figura 3.4: Distribuição do vento durante os meses de fevereiro de 1975 a 1981.

$$V = \sum_i f(V_i) \times V_i = 7{,}89/s$$

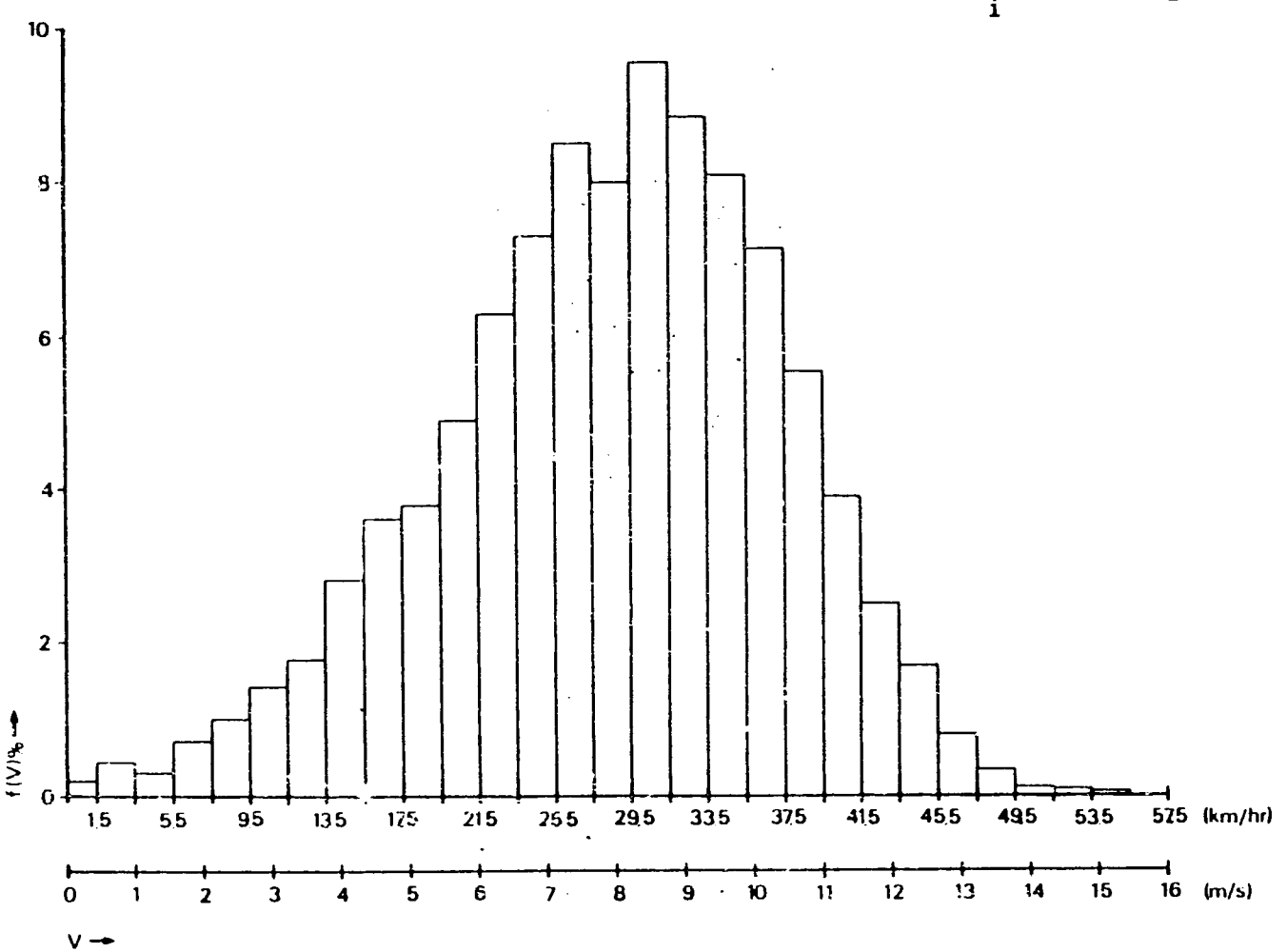

Fig. 1. Wind speed distribution at Praia airport for February (average of years 1975 to 1981). From Pieterse [2]. The average wind speed is 7.89 m/s and the Weibull shape parameter is 3.6.

FIGURE 4-3

SITE A-01 ALAMEDA COUNTY

DATA PERIOD : 2/22/79 - 12/31/79

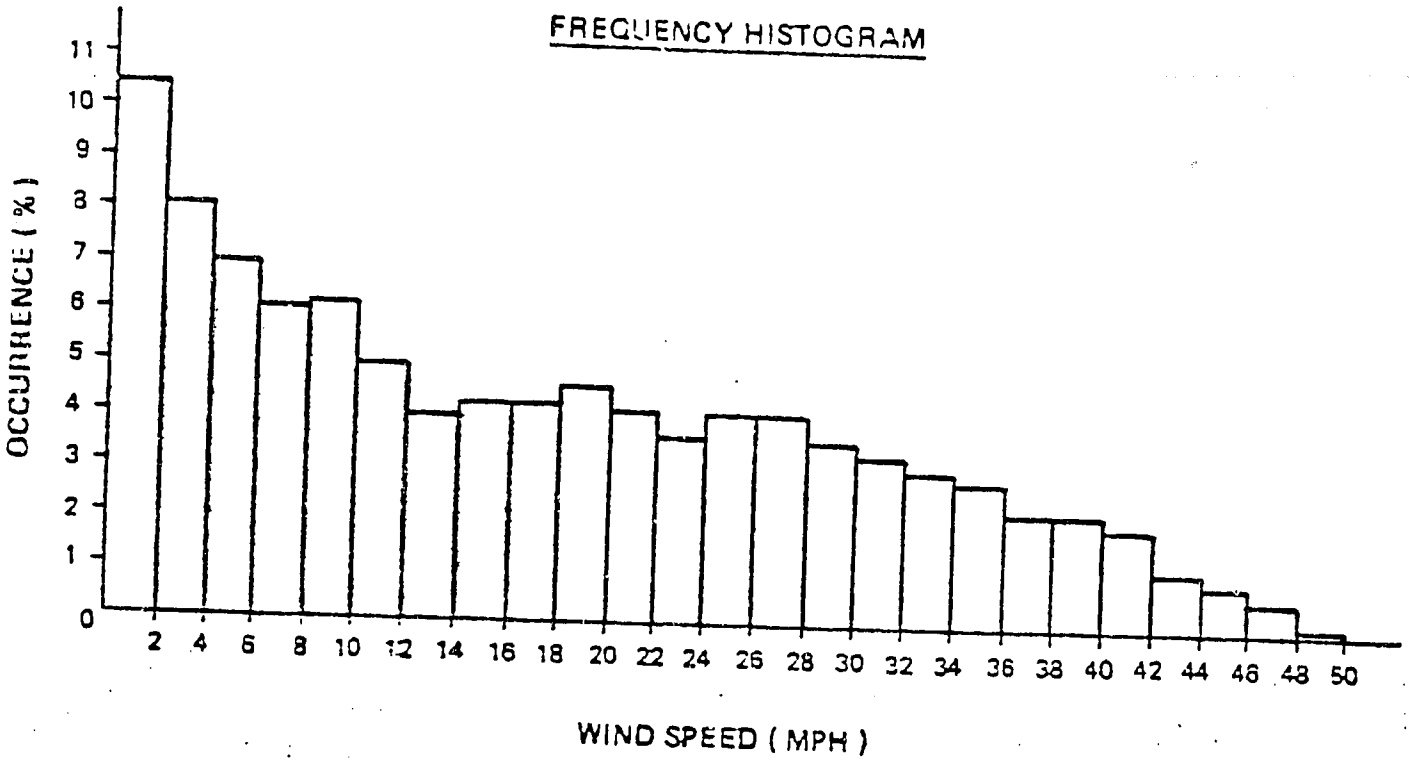

Fig. 2. Wind speed distribution at Site A-01, near Altamont Pass east of San Francisco, California, U.S.A. for March through December 1979. The average wind speed is 7.4 m/s and the Weibull shape parameter would be near unity but the data fits the Weibull distribution poorly. From Hennessey and Waco [11].

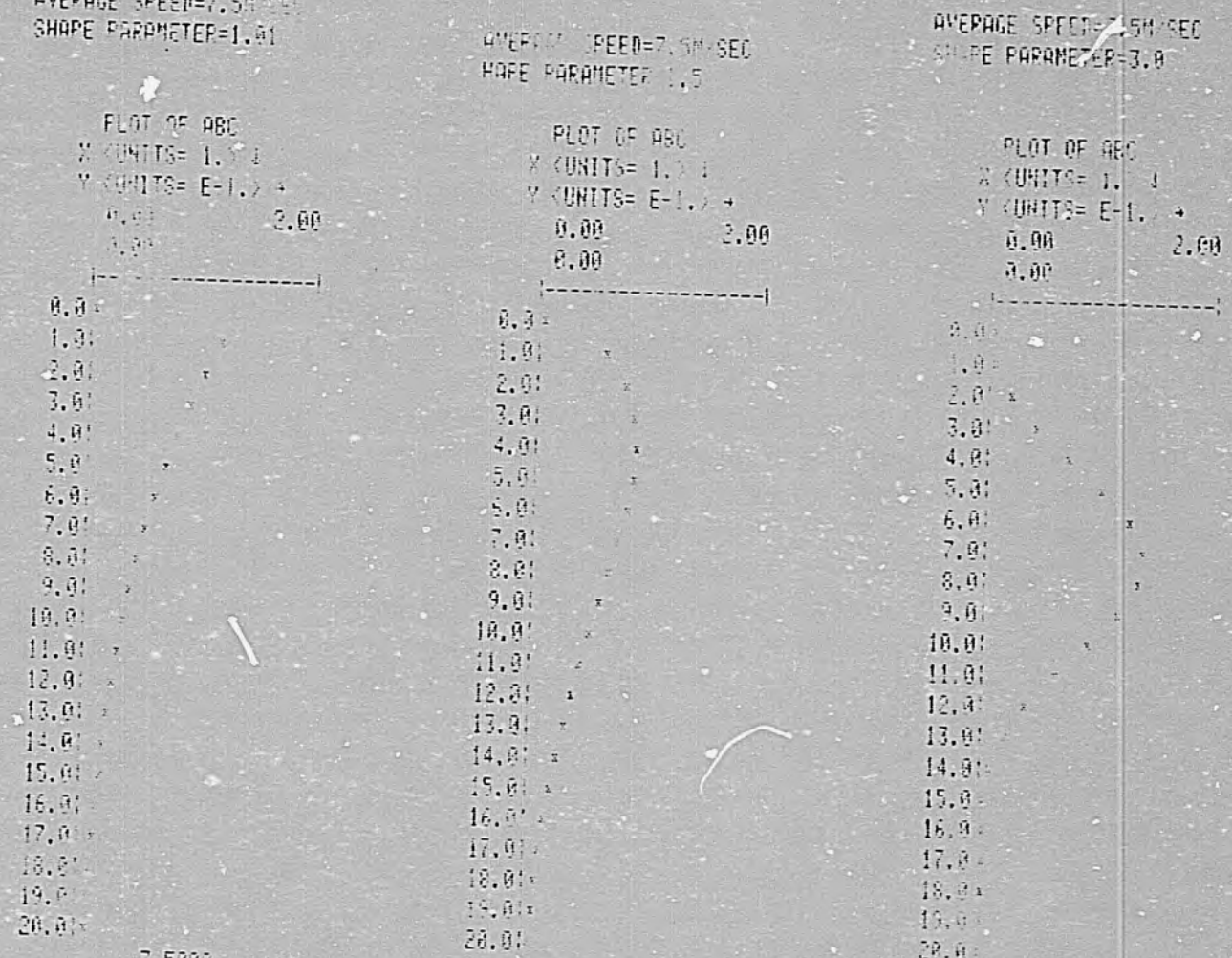

Fig. 3. Weibull distributions for $\overline{V}$ = 7.5 m/s, k = 3.00, 1.50 and 1.01 (top to bottom). The vertical axis runs from 0 to 0.2. The horizontal axis from 0 m/s to 20.0 m/sec.

3. Wind machine performance

It is useful to estimate performance of wind electric machines in Cape Verde by comparison to the performance of machines in the Altamont Pass area where over 500 machines of 50 to 100 kW rated power are operating. The average wind speeds are similar. However, because of the very different wind speed distributions the experience at Altamont Pass must be applied to Cape Verde cautiously.

Let us use, as an example, the Fayette Model 34-75IIS wind machine [13] with a rated power of 74 kW. More than 200 of these are in operation in Altamont Pass. It has a 10.4 meter diameter rotor with three fixed blades. It feeds power into the northern California electric distribution system. At low wind speeds its rotation speed is 80 revolutions per minute (RPM), at higher wind speeds it is 120 RPM. It's power curve (power output as a function of wind speed) is shown in Figure 4. Superimposed on this figure are two idealized power curves [see refs. 10, 12] which will be used for subsequent energy output calculations.

A straightforward numerical integration of the product of the actual (not idealized) power curve and the annual wind distributions of site A-01 near the Altamont Pass (Figure 2) and of the Praia airport* results in predicted annual electrical energy production of:

Site A-01 near Altamont Pass	167.000 kWh
Praia Airport	114.000 kWh

Thus, this wind machine produces 45 % more energy at the U.S. site where the <u>average wind speed</u> is not much different from Praia.

The reason is that this machine is designed for the higher speed tail on the wind speed distribution for Altamont Pass (Weibull shape parameter near unity). There are fewer occurrences of such higher wind speeds at Praia (shape parameter near three) as one can see by comparing the distributions for the two sites.

The power curve of a wind machine can be satisfactorily approximated by the simple form shown in Figure 5. The machine begins producing power at a "cut-in" wind speed, V_1, and the power rises linearly with wind velocity up to a "rated" windspeed, V_2 and "rated" power P_r. Then it is constant up to a "cut-out" wind speed, V_3 [10, 12]. The power curve of the Fayette machine can be approximated by a curve of this type with V_1 = 5 m/s, V_2 = 17 m/s and P_r = 74 kW. This curve is superimposed, in solid lines, on the power curve of Fayette machine (Fig. 4) and it can be seen to approximate it reasonably well. The Fayette machine does not have an abrupt "cut out" speed but we shall assume it to be 30 m/s, recognizing that the exact choice makes little difference for energy pro-

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* The sum of the monthly curves similar to Figure 1 [as given in Table 3.1 of ref. 2].

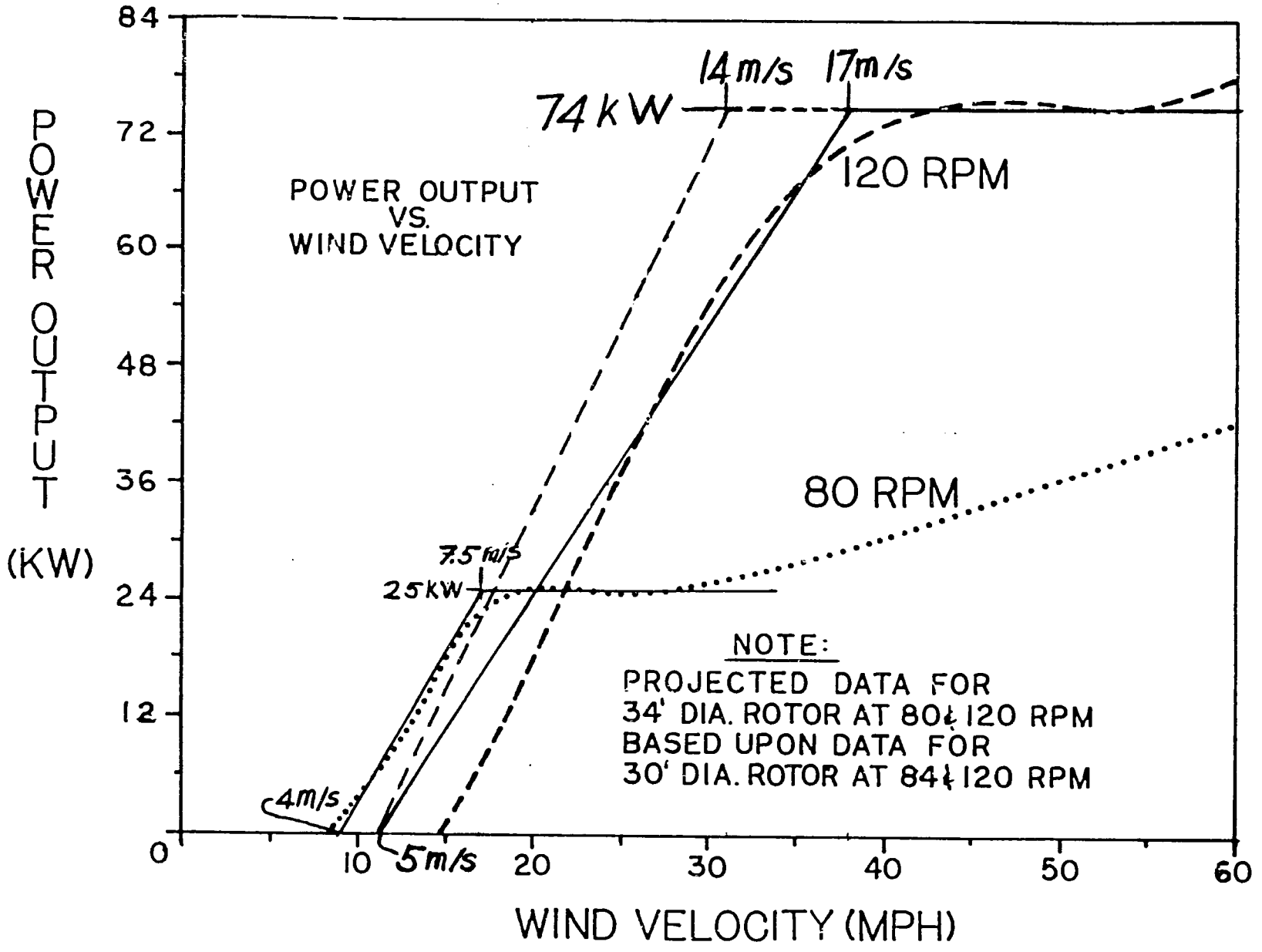


Fig. 4. Power curve of a Fayette wind electric generator. Three idealized power curves are also shown. Courtesy of J. Moore [13].

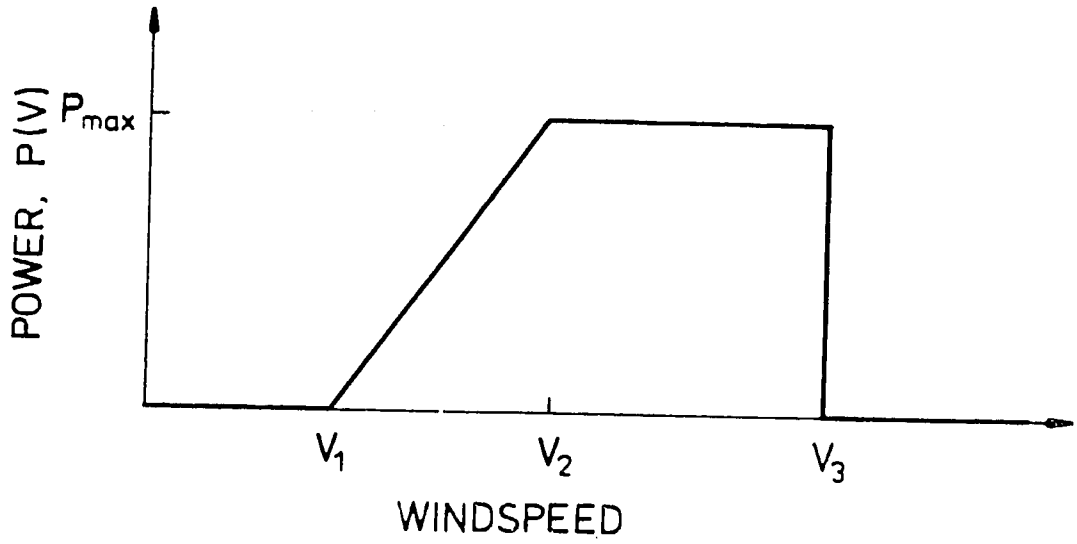


Fig. 5 Idealized power curve.

duction since winds of this speed seldom occur.

The Windatlas for Denmark [12] gives a simple method for calculating the energy output of a machine having this simple power curve at a site having a Weibull wind speed distribution [see pages 106-109 of ref. 12]. The product of the Weibull function (Eq.1) and the power curve of Figure 5 is integrated over all wind speeds. The result is the average power, $\overline{P}$,

$$\frac{\overline{P}}{P_r} = \frac{G_h(V_1/c) - G_h(V_2/c)}{V_1/c - V_2/c} \qquad (2)$$

The G's are certain gamma functions of the velocities, V_1, and V_2, and of the Weibull parameters c and k. The average velocity comes in through the relation [10, 12]

$$c = \overline{V}/\Gamma(1+1/k) , \qquad (3)$$

where Γ is the gamma function. The G's are given in Table A6 of the "Windatlas" [12]. We have used k = 2.5 since the "Windatlas" table doesn't give G's for higher values. We have omitted a term from Eq.2 as given in the Windatlas because it is negligible for k values of 2.5 and cut-out wind speeds of 30 m/s. A shape factor of 2.5 should be a reasonable representation of the situation at Praia since Pieterse [2] gives shape factors ranging from 2.24 in September to 3.67 in May.

We have used this method to calculate the average annual power and annual energy production for a machine of the Fayette type with V_2=17 m/s and V_3=30 m/s; and for a machine modified so as to reduce the cut-in speed, V_2, to 14 m/s in order to better take advantage of the Praia wind distribution. The results are shown in Table IV-1.

TABLE IV-1. Average and monthly energy production for a wind electric generator. The wind machine has the power characteristics of Figure 5 and the probability density function for windspeed is the Weibull function, Eq. 1, with a shape factor $k = 2.5$.

$\bar{V}$(m/s)	V_2 = 17 m/s			V_2 = 14 m/s		
	$\bar{P}/P_r$	$\bar{P}$(kW)	E(MWh/m)	$\bar{P}/P_r$	$\bar{P}$(kW)	E(MWh/m)
5	0.072	5	3.6	0.096	7	5.0
7	0.201	15	10.8	0.258	19	13.7
9	0.347	26	18.7	0.445	33	23.8
11	0.490	36	25.9	0.593	44	31.7
13	0.604	45	32.4	0.699	52	37.4
15	0.692	51	36.7	0.772	57	41.0

$\bar{V}$ = average wind speed
V_1 = cut-in wind speed (5 m/s)
V_2 = rated wind speed
V_3 = cut-out wind speed (30 m/s)
$\bar{P}$ = average power
P_r = rated power
E = monthly energy production ($720\bar{P}$)

It is immediately evident that, in Praia, it is quite important to select a machine with a lower cut-in speed. At an average wind speed of 9 m/s, for example, the machine with the 14 m/s cut-in speed will produce 27 % more power than the one with a 17 m/s cut-in speed. Thus, in selecting a wind machine for Praia we would choose a machine with different characteristics than one operating in the Altamont Pass (or in other similar northerly wind regimes). With precautions such as these we can transfer a great deal of our quantitative, operating information from the operating wind farms of the U.S.A. or Europe to Cape Verde.

If one knows the characteristics of a wind electric generator, i.e., Pr. V_1, V_2, V_3 and has the average wind speed for the month at a site in Cape Verde one can read the monthly energy production from a table such as Table IV-1. At a site such as Praia airport at 10 meters height one would be able to produce about 13,700 kWh in June ($\bar{V}$=6.78 m/s) with the machine which has a rated wind speed of 14 m/s. If all months of the year were the same as June this would be about 164,000 kWh/year. However, as Pieterse shows [2], the last six months of the year are poorer wind months. Actual numerical calculation from Table 3.1 of Pieterse [2] for this machine (V_2 = 14 m/s) at Praia airport yields 92,000 kWh/year.

It would be expected, of course, that a location such as Ponta d'Agua would produce more energy than this because of the speed up effect over a properly oriented and shaped ridge. Results of measurements currently being made should allow reliable quantitative estimates to be made which can be validated by direct comparison to results from operating wind farms.

4. Cumulative wind distribution:

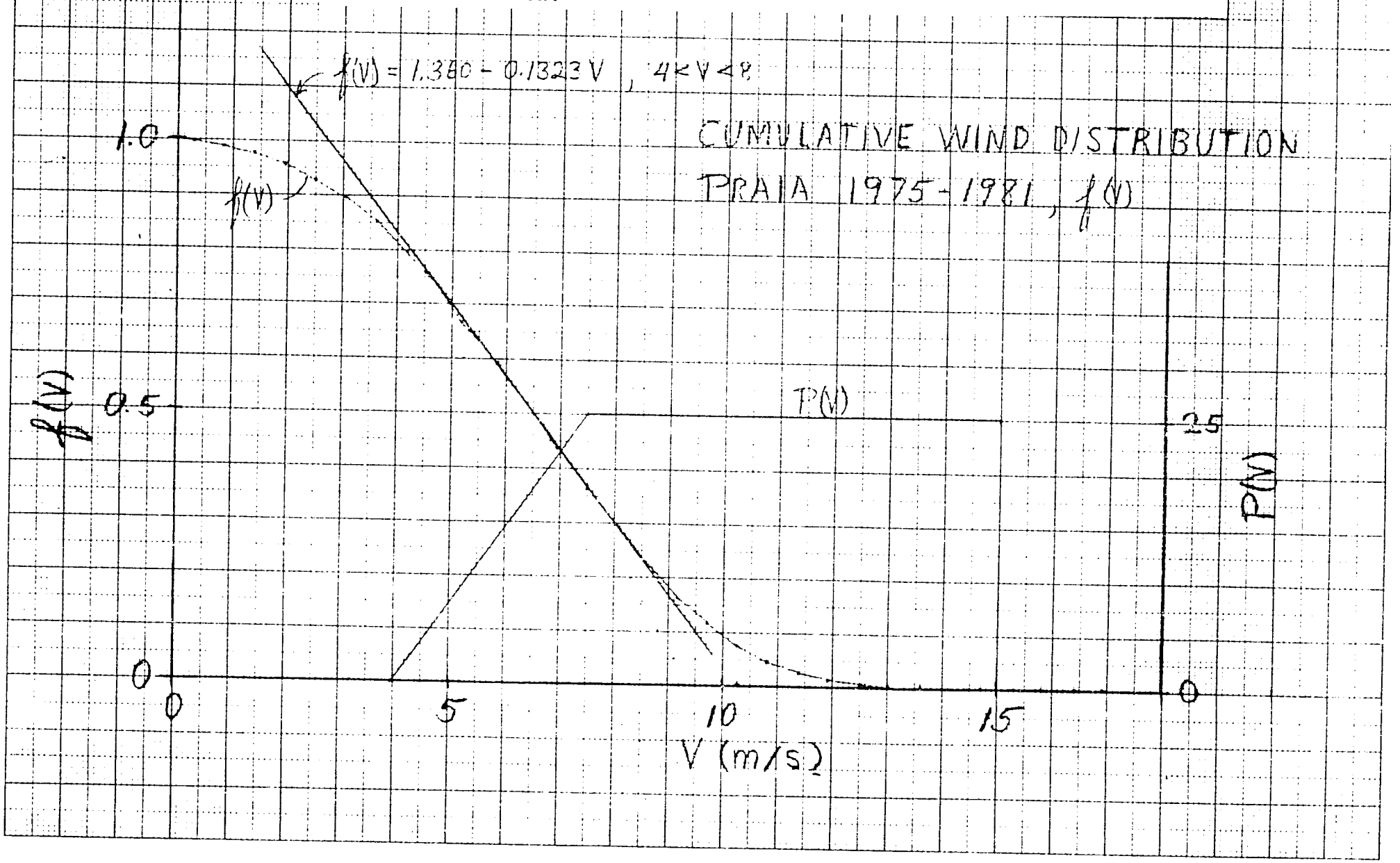
The cumulative wind distribution is the fraction of the time that the wind speed is above V. It is particularly useful for estimating and calculating the percentage of time that a wind machine will be producing power.

The cumulative distribution for the Praia airport is shown in Figure 6. It is the distribution for 6 years from 1975 to 1981 as taken from Table 3.1 of Pieterse [2]. In his report Pieterse gives the cumulative distribution for each month separately for these six years.

Let us use this distribution to calculate the power and energy produced by the Lafayette windmill in its 80 RPM mode. A good approximation to its 80 RPM power curve is

$$P(V) = 0 \qquad 0 < V < V_1$$
$$P(V) = P_r(V-V_1)/(V_2-V_1) \qquad V_1 < V < V_2$$
$$P(V) = P_r \qquad V_2 < V < V_3$$
$$P(V) = 0 \qquad V_3 < V < \infty$$

Fig. 6. Cumulative wind distribution for Praia airport for the years 1975-1981 (from Pieterse [2]). A linear approximation in the speed range 4 to 8 m/s and a power curve of a windmachine having $V_1 = 4$ m/s, $V_2 = 7.5$ m/s, $P_r = 25$ kW, $V_3 = 15$ m/s are superimposed on the distribution.



We have chosen $V_1 = 4$ m/s, $V_2 = 7.5$ m/s, $V_3 = 15$ m/s, $P_r = 25$ kW. This power curve is superimposed on Figures 4 and 6.

The cumulative distribution function can be fitted, by least squares, to a straight line over the range of velocities 4 m/s to 8 m/s. The line is

$$f(V) = a - bV \qquad a = 1.3601, \quad b = 0.1323 \qquad 4 \text{ m/s} < V < 8 \text{ m/s}$$

with a coefficient of determination $r^2 = 0.9988$ which indicates a very good fit.

From the superposition of P(V) and f(V), Figure 6, one can determine that the machine produces

zero power	20 % of the time
zero to 1/2 power	21 % of the time
1/2 power to full power	22 % of the time
full power	37 % of the time

The energy, in kWh, produced during a certain time period is

$$E = N \int_0^\infty - \frac{df(V)}{dV} P(V) dV$$

where N is the number of hours in the period (= 8760 hrs/year). This equation is easily integrated using the forms of P(V) and f(V) above. The result is

$$\boxed{E = NP_r \left[a - \frac{b}{2} (V_2 + V_1) - f(V_3) \right] .}$$

The parameters in this expression are presented above and the value of $f(V_3)$ is read from the cumulative distribution function. For Praia, $f(V_3)$ will probably be zero for most wind machines since $V_3 > 13$ m/s for most machines. The energy per year at Praia airport at a height of 8 meters is

$$E = 8760 * 25 \left[1.3601 - \frac{0.1323}{2} (7.5 + 4) - 0 \right] = 131{,}263 \text{ kWh/year}$$

This very simple procedure is possible because the wind speed data fits a cumulative distribution curve which is accurately a straight line between 4 and 8 m/s and because the wind machine has its V_1 and V_2 lying within this straight line region.

For the wind speed regime at the Praia airport the energy produced is extremely sensitive to the low wind speed behavior of the machine. A low cut in speed, V_1, and a low rated speed, V_2, are desirable. It is striking that the approximation to the 75 kW curve used earlier produces less energy than this approximation to the 25 kW curve. The comparison is:

$V_1 = 5$, $V_2 = 17$,	$P_r = 75$ kW	E = 114,000 kWh/year
$V_1 = 4$, $V_2 = 7.5$,	$P_r = 25$ kW	E = 131,000 kWh/year

The 25 kW machine produces more energy than the 75 kW machine because it performs better at low wind speeds.

Cost of electrical energy produced by wind:

Let us assume that the windmill with $V_1 = 4$ m/s, $V_2 = 7.5$ m/s and $P_r = 25$ kW can be purchased, shipped and installed near Praia airport for 60,000 USD* and that it will produce 130,000 kWh annually. Assume its life to be 20 years and the interest rate to be 10 %. Also assume annual maintenance and operation costs to be 1000 USD/year. Then the annual cash flows are:

Payment on capital (20 year, 10 %)	7050 USD
Operation and maintenance	1000 USD
Cost of producing electricity (8050/130,000)	0.062 USD/kWh

A location on a ridge or hill or on a higher tower would be expected to produce more energy and consequently energy costing less than this.

Unfortunately, long term wind speed measurements on ridges and desirable wind power locations are not available to us at the moment nor are detailed data on power curves and costs, including shipping, installation and operating costs, of various commercial wind machines. Therefore it is not possible at the moment to do a more precise calculation of wind electric energy production costs. However, it is evident that wind electricity costs are of the same order of magnitude as the diesel fuel saved (about 0.08 USD/kWh).

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* This is an estimated cost based on reports of costs of commercial wind electric generators from the United States and Denmark.

4. References

1. "Anuário Climatológico de Portugal", Serviço Meteorológico Nacional, Lisbon. I Parte, "Continente e Ilhas do Atlântico Norte" before about 1959, and II Parte "Territórios Ultramarinos" after 1959. The "Anais Meteorológicos das Colónias", Ministério das Colónias, Lisbon, was cited by two authors [2, 6] but we did not obtain copies of it. It may contain measurements from the same stations as the "Anuário Climatológico de Portugal".

2. Pieterse, Niko, "Caudais estimados das aerobombas baseando-se nos dados do vento da Praia -Relatório VI", Ministério do Desenvolvimento Rural, Praia (1982).

3. Dong, Yen H. (editor), "Study of Wind Power Generation for Sal Island", Burns and Roe Industrial Services Corporation, Paramus, NJ, U.S.A. (1980).

4. Beurskens, H.J.M., Wind energy for water pumping in Cape Verde.

5. Van Meel, Joop, "Relatórios acerca do aproveitamento das energias renováveis em Cabo Verde, 1ª Parte", Ministério do Desenvolvimento Rural, Praia (1981).

6. Blake, Steve, "Wind energy resources in the Cape Verde Islands", Route 1, Box 96-A, Oskaloosa, Kansas 66066, U.S.A. (1979).

7. National Climatic Center
Asheville, North Carolina 28801, USA

8. Frandsen, S., "Danida Mission to the Cape Verde Islands Concerning Wind Turbines for Electricity Production", RISØ National Laboratory, DK-4000 Roskilde, Denmark (1981).

9. Lambert, Yves, "Evaluation des Energies Renouvelables pour les Iles du Cap Vert", Ministère de la Coopération, Republique Française, Praia (1977).

10. Justus, C.G., "Winds and Wind System Performance", The Franklin Institute Press, Philadelphia (1978).

11. Hennessey, Joseph P., Jr., and Waco, David E., "A Strategy for Low-Cost Wind Prospecting", California Energy Commission, 1516 9th Street, Sacramento, California 95814; (1982); and unpublished data furnished by Mr. Waco (1983).

12. Petersen, Erick Lundtang, Troen, Ib, Frandsen, Sten, and Hedegaard, Klaus, "Windatlas for Denmark", RISØ National Laboratory, DK-4000 Roskilde, Denmark (1981).

13. Moore, James M. and Rich, Earle L. Fayette Manufacturing Company, Tracy, California (1983).

V. COSTS OF PETROLEUM FUELS IN CAPE VERDE

Petroleum fuel prices have stabilized in many countries during the past few years. However, in Cape Verde they have increased considerably during this time and continue increase. This can be attributed to the deteriorating CVE/USD exchange rate since petroleum must usually be purchased with U.S. dollars. This increase has profound implications for the viability of renewable energy systems. This information is found in Appendix B.

VI. PERFORMANCE OF RENEWABLE ENERGY TECHNOLOGIES IN CAPE VERDE

There are two types of renewable energy technologies which have enough of a track record in Cape Verde to allow an evaluation of their performance and an estimation of their future prospects. These are wind driven water pumps and simple solar stills. Other renewable energy devices and systems have been installed but only recently or as very small laboratory-type trials so that little useful operational data is available. Among the latter may be mentioned:

(1) A 2.2. kW photovoltaic water pump installed by I.N.I.T. at Porto Mosquito.
(2) A very small biogas digester installed by I.N.I.T. at São Filipe.
(3) A solar hot water system at the Hotel Morabeza.
(4) A very large, 580 cubic meter, biogas digester at the State pig farm at Santa Cruz under construction.
(5) A number of commercial wind electric generators are being tested by D.E.R. at São Filipe.

1. Wind powered water pumps:

About forty of these have been installed by D.E.R. They are commercial Dempster and Southern Cross models. Five units constructed by JOTE-NAVE, Mindelo have been ordered. They are similar to the American-style wind pump and manufactured almost entirely in Mindelo. This includes casting and milling of gears and construction of brass pumps as well as performance of all iron work. D.E.R. has designed and constructed a water pumping windmill which is expected to be more efficient than standard models and constructable in Cape Verde.

Detailed information on wind powered water pumping in Cape Verde is available in D.E.R. reports [1, 2, 3, 4]. An evaluation of the program is to be made soon. Presumably, this will include a technical and economic evaluation of this pumping technology.

2. Simple solar stills: The simple solar still consists of a shallow container of water with a sloping transparent cover. Solar radiation enters and is absorbed by the water and its container. Water evaporates and condenses on the transparent cover. The condensed water droplets adhere to and run down the under side of the cover into a collecting trough. It is a "single-effect" device meaning that the incoming energy is only used once (multi-effect devices use the heat liberated by the condensing water to vaporize more water and this can be repeated many times thereby utilizing the energy more efficiently). This type of still will produce one cubic meter of water per square meter of still in one year if it is operating well and in a sunny climate. As the transparent cover becomes dirty and vapor leaks develop production will decrease. A considerable amount of labor is required to keep the still clean, maintained and operating.

We observed the remains of two relatively large simple solar stills in Cape Verde*. One of about 750 square meters was at the Hotel Morabeza on Sal Island and the other of about 60 square meters was on the lighthouse point near Praia. The basins of both were constructed of concrete and they both had been covered with glass at the time of disuse.

The still at Hotel Morabeza was built in 1966**. For its first four years of operation it was covered with tedlar, an ultraviolet resistant plastic, which was supported by a low pressure air pump. The tedlar began breaking within a year due to drying and flexing in the wind and frequent replacement was needed. After four years the plastic was replaced by the undulating type of glass used in bathrooms (shower doors). This was expensive especially because of breakage as high as 2/3 during shipping. After three more years, operation was discontinued and a diesel powered reverse osmosis unit installed.

The original cost of this solar still was 1.5 million Belgian francs or (at an exchange rate of 50:1) about 40 U.S. dollars per square meter. Mr. Baert said it produced 3 1/2 tonnes of water per day averaged over the year. This would be close to 1.7 tonnes per square meter per year which is considerably higher than reported production from operational solar stills elsewhere (0.8 to 0.9 tonnes/m2 year)*** It should be noticed, in this connection, that insolation in Cape Verde is not exceptionally high (see section III).

The still was operated by one person. Sea water was first allowed to remain for some time a settling basin. The still was filled before sunrise and it was drained in the evening.

We cannot calculate the actual cost of water from this still because we do not have the costs of replacing the plastic and glass. However, it is possible to estimate a minimum cost assuming no replacement parts or material at all. We will consider this still with a tedlar cover and assume it lasts for the life of the still. The construction cost is 30,000 U.S. dollars (1.5 million Belgian francs). A ten year life with no repairs will be assumed. Assume a ten year loan of 30.000 U.S. dollars at 10 % interest. Assume that the operator is paid 700 U.S. dollars per year and that management costs are 300 U.S. dollars per year. Then the annual cash flows are, in U.S. dollars:

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* Two other small simple solar stills, of about two square meters area, are at São Filipe (D.E.R.) and Praia (I.N.I.T.). They are laboratory types from which no significant operational information is available.

** Information provided by Beaudouin Baert of the Morabeza Hotel. Mr. Baert is actively pursuing other renewable energy activities including solar hot water for the hotel.

*** 1860 square meter still at Awanea, India, 1979. AID Desalination Manual p. 7-12.

Equal annual payments on the loan	4882
Labor	700
Management	300
Total annual cash flow	5882

At the reported production of 1280 tonnes per year the cost of water is 4.60 U.S. dollars per tonne. This is a lowest, and quite unrealistic, figure. Operational experience showed that the lifetime is less than ten years and that plastic and glass replacement was a significant cost. Furthermore, the reported water production figure is much higher than experience elsewhere and construction costs have increased considerably since 1966. Taking these things into account we have:

Equal annual payment on the loan (assuming 50 % increase in construction costs since 1966)	7323
Labor	700
Management	300
Glass replacement and other repairs (including labor, shipment, breakage)	1000
Total annual cash flow	9323

Taking annual production to be 750 tonnes per year (still optimistic) we find the cost of water to be 12.43 U.S. dollars per tonne.

We have no cost or operating information on the second large still referred to above. It appears to have been out of use for many years. It's construction cost per square meter appears to be higher than the still at Hotel Morabeza because of more massive construction which required considerably more concrete per square meter of still area.

It is noteworthy that estimates of construction costs and water costs of solar stills are frequently much lower than actual costs. For example, Van Meal [1, annex D] gives an estimate derived from a study by Aerowatt (France) for a solar desalinator at Bahia das Gatas, São Vicente from which water would cost 85$00 per tonne. This is 4 to 10 times less than the costs of water from the solar still at Hotal Morabeza. It is also less than the cost of water from the large modern desalination plant at Mindelo (141$00 per tonne as given by ELECTRA).

3. Conclusions

Wind powered water pumps and simple solar stills are the only two renewable energy technologies with enough actual operating experience to allow estimation of their future place in the Cape Verdean energy picture. Wind water pumping appears to be promising [1,2,3,4]. On the other hand simple solar stills appear to be plagued by deterioration of and breakage of cover materials, and require a great deal of attention for operation, maintenance and repair. Even more serious, the construction cost is high relative to the quantity of water produced.

The latter factor alone causes the cost of the water to be quite high. Taking account of all costs that actually occur raises the cost of water to above ten U.S. dollars per tonne.

The basic problem with the simple solar still is that it uses its energy only once. Therefore vast areas have to be covered with concrete and glass; and only a small amount of water comes out. On the other hand there are other desalination methods which utilize energy much more efficiently. Their source of energy is usually petroleum but prospects for substituting solar and/or wind energy are good.

The simple solar still cannot compete with more efficient desalination methods except perhaps in certain small and remote locations where water is very difficult to obtain by any other means. It could also be useful in cases where a small amount of reasonably well-demineralized water is needed for which a good price exists such as water for car batteries.

VI. REFERENCES

1. Van Meel, Joop, "Relatórios Acerca do Aproveitamento das Energias Renováveis em Cabo Verde", 1ª Parte Relatórios Gerais, Application of Renewable Energies in Cape Verde (1978). 2ª Parte Relatórios acerca das Ilhas (1977-1981), MDR, Praia.

2. Projecto Energias Renováveis, Relatório (1980), MDR, Praia.

3. Versteegh Kees, Relatório Sobre Status de Aerobombas (1981), MDR, Praia.

4. Pieterse N.N.W., Teixeira Manual da Graça, and Livramento D.R., Report V: Progress April-June 1982, Report VIII: Progress October-December 1982. Report XII: Progress January-March 1983, MDR, Praia

VII. TECHNICAL AND FINANCIAL EVALUATION OF SOME RENEWABLE ENERGY TECHNOLOGIES FOR CAPE VERDE

We have discussed energy needs (Sec. II) and energy resources (Secs. III, IV, and V). It remains to discuss the means for converting the resources to forms of energy that satisfy the needs. These are energy technologies or devices. Wind machines convert wind energy to mechanical or electrical power which satisfies water pumping, lighting, etc., needs. Solar ponds convert solar radiation to heat which can drive a multistage flash evaporation desalination plant, for example, or to electrical energy which can drive a reverse osmosis desalination plant or a multitude of other things in satisfaction of energy needs.

It is the conjunction of (a) significant energy need, (b) good energy resource and (c) good technology to connect the energy resource to the energy need that determines our choice of technologies that we will consider in some detail. It is not hard to justify the choices made because they are relatively obvious. It is harder to say why some things have been left out. First, we leave out most things, all biomass energies except cooking fuels, O.T.E.C., wave energy, animal power, etc. because we arbitrarily place them outside the domain of energy technologies we wish to consider. Others, such as solar hot water, do not have a large demand in Cape Verde. There is no good technology at the moment to connect solar energy to mobile power for transportation and agricultural needs which require liquid fuels (biomass has already been excluded). Thus we arrive at a small promising group which is essentially electricity and water production by wind machines, solar ponds and photovoltaics for small (present) and large (future) applications. The other promising area selected is improved stoves and cooking methods.

These are analyzed primarily on a technical and financial basis but other considerations such as building local industry, improving the quality of soils, and reducing tedious and time consuming labor are also considered. The analyses are made in the following several subsections. Then in Section VIII, projects which logically issue from these analyses are recommended.

1. Photovoltaic electricity.

Photovoltaic cells convert solar radiation directly into electrical energy with no moving parts. They have the attractive properties:

- very low maintenance - can be left for long periods in remote locations without attention.
- simple to install and repair - panels can be replaced while system is operating.
- long life.
- modular construction - can be added to easily without shutting the system down.
- versatile & convenient - energy comes out directly as electricity.
- light weight - does not require as much space as most solar electricity producing devices.
- smaller units such as 250 watts are portable if desired.

They have the following deficiencies:

- they produce energy only when the sun shines.
- they are expensive.

The first deficiency is of little concern when used for waterpumping since the water can be stored at nominal expense. When used for electricity production, however, batteries must usually be used for storage. This is a substantial expense, and also consumes part of the energy. The other major problem, the high cost of about 10 USD per peak watt is more serious. However, the costs have come down dramatically and are predicted to continue to decrease.

Presently photovoltaics are the most convenient and economical means of producing electricity for small, e.g., zero to several hundred watt applications that do not have access to an electrical distribution network. This is especially true if high reliability is needed and if the installation must function with minimum, or no, attention for long periods. Small internal combustion electric generators, although cheaper to install initially, require a steady fuel supply, constant attention and periodic overhauls (or replacement) and are being replaced by photovoltaics for small, remote applications.

Photovoltaics are being used widely for remote communications sites (radio and microwave repeater sites), and for lighting and radio power in remote dispensaries (for example in Lesotho). They are beginning to be used for remote medical refrigerators as components of vaccine and medical cold chains. They are replacing kerosene fired refrigerators in this application. There are even about 100 photovoltaic water pumps in West Africa at this time. However, their price is still too high to economically compete with diesel pumps except for small units and special cases. As the price of photovoltaic systems decreases they can be expected to assume more functions and especially to take over many higher power applications, e.g., remote water pumping at ten or more kilowatts.

The most appropriate applications at present in Cape Verde are remote, low power, installations for illumination, communications, and refrigeration. We did not determine the extent of this need although we were told that most rural dispensaries are in locations which have access to electric power and telephones and this may not be a significant need. A second appropriate application is for small water pumps in locations with poor wind speeds. A great deal of water pumping is needed in the ribeiras and these are more or less shielded from the wind. Beurskens [1] uses an average wind speed for north-east-directed ribeiras which is 7/10 of the average wind speed on the Praia airport achada. He finds that under these conditions wind water pumping is much cheaper that photovoltaic water pumping. However, many achadas are not oriented north-eastward and would be expected to have lower wind speeds. When coupled with expected price decreases photovoltaics may be competitive with wind water pumping in such locations.

At present prices, photovoltaics are no competition to wind, diesel or solar pond systems for generation of electricity on a large scale for cities or for desalination plants. The price would have to fall to 1 or 2 USD per peak watt (for the entire photovoltaic system) in order to compete with wind generated electricity at a good wind site. However such price reductions have been predicted (for example, see U.S. news and World Report, p. 45, May 2, 1983) many times and there is good reason to believe that price reduction to this level is possible.

Because it is presently the best solution for certain small remote applications, shows promise for certain intermediate sized applications, and would be an extremely vigorous competitor for large scale electricity production if the predicted price decreases occur, it is wise to "keep the foot in the door" and have a photovoltaic program in the country.

References:

1. H.J.M. Beurskens, "Wind energy for water pumping in Cape Verde" S.W.D., P.O. Box 85, Amersfoort, The Netherlands (1981).

2. Solar ponds:

Two aspects of solar energy have greatly inhibited its development as a direct source of energy for human use. It is weak and it is intermittent. At best the earth's surface receives about one kilowatt of solar energy per square meter and this does not arrive at night or during cloudy periods. Therefore, solar collectors must cover large areas and, for most uses, energy must be stored for use later. Large area collectors and energy storage are both expensive. For example, standard flat plate collectors, as used for water heating, cost about 200 to 400 USD per square meter when installed. Heat storage, as hot water, costs 100 to 200 USD per tonne of water (or 0.5 to 1.0 USD/MJ for a water temperature change of 50°C).

The solar pond reduces both of these costs. The solar pond collects and stores solar energy for 20 to 70 USD per square meter and this includes heat storage by one tonne of water per square meter of pond (2×10^8 J/m^2 for a 50°C temperature change). Therefore, a solar pond can collect and store solar heat, at temperatures up to 100°C, for about a tenth of the cost of the conventional flat plate collector - water reservoir system (However, solar ponds would not be possible for smaller installations such as solar hot water heaters for single dwellings). This low cost collection and storage capability is its main attractive feature.

Description of solar pond:

When an ordinary pond of water absorbs solar radiation the deeper water as well as the surface water is heated. Heat is lost quickly from the surface water by evaporation, radiation and conduction. The heated deeper waters become less dense due to increased temperature and rise to the top where they are cooled in the same way. Therefore, the entire pond remains at a temperature near or slightly below the air temperature.

The salt gradient solar pond is a body of water whose salt concentration increases with depth. The salt concentration gradient is maintained at a strength sufficient to maintain a positive density gradient, measured downwards, even when the lower layers of water are heated. Thus solar energy penetrating to the bottom of the pond and heating the water there is not convected upward. Since water is a reasonably good thermal insulator (K = 0.64 W/m °C) and opaque to infrared radiation, the heat of the bottom water is lost very slowly. The pond can store solar heat for many months. Its collection efficiency is in the range 15 - 25 % at practical operating temperatures of 90°C [1]. Maximum temperatures above 100°C have been attained [2].

The heat can be removed by either an internal or external heat exchanger. The heat can be used for any requirement for heat up to 100°C or for driving a low temperature thermal engine to produce me-

chanical or electrical power.

It turns out that the salt concentration and temperature do not increase monotonically with depth. Natural mixing processes at both the bottom and top cause mixed or convective zones at the bottom and top in which the temperature and density are almost uniform [3, 4]. The middle, non-convective or "gradient" zone, where the temperature and density increase with depth, forms the insulating zone that prevents loss of heat from the lower, or heat storage, zone. A diagram of this "standard" salt gradient pond is shown in Figure VII-2.1. The thicknesses of these two zones are adjusted to suit the requirements of the application (of the order of 1 meter each). The upper convective zone, caused by wind and thermal cycling, is detrimental to pond performance and one tries to make it as thin as one can.

For details of the physics and operation of solar ponds the reader is referred to the literature [5-13]. For our purpose we need only to list some of their advantages and disadvantages in order to see if and where they can reasonably be used in Cape Verde.

Qualities of solar ponds:

(1) Low cost per unit area as discussed above.

(2) Long term heat storage. To collect and store a given quantity of solar heat at about 90°C costs about one tenth of that of the flat plate collector-water reservoir system.

(3) Its surface does not need cleaning, dirt and dust settle to the bottom with no ill effects. However, measures must sometimes be taken to kill biological growth which would diminish the transparency of the water.

(4) It is easy to transport the heat to a central point. Only one inlet and one outlet pipe, both on the same side of the pond [9], are needed. Ordinary collector fields (except for the optically collected or "power tower" type) need extensive arrays of insulated pipe which are both expensive and lossy.

(5) The pond can be built mostly with local labor and materials in Cape Verde. The most expensive imported items will be the plastic liner and the salt. Although the plastic must be imported salt is locally produced.

(6) Maintenance and operation of a pond will require the skills of no more than a good swimming pool maintenance person. Unusual events can be referred to a central laboratory or office. Since ponds deteriorate slowly [4], ample time to effect corrective measures is available.

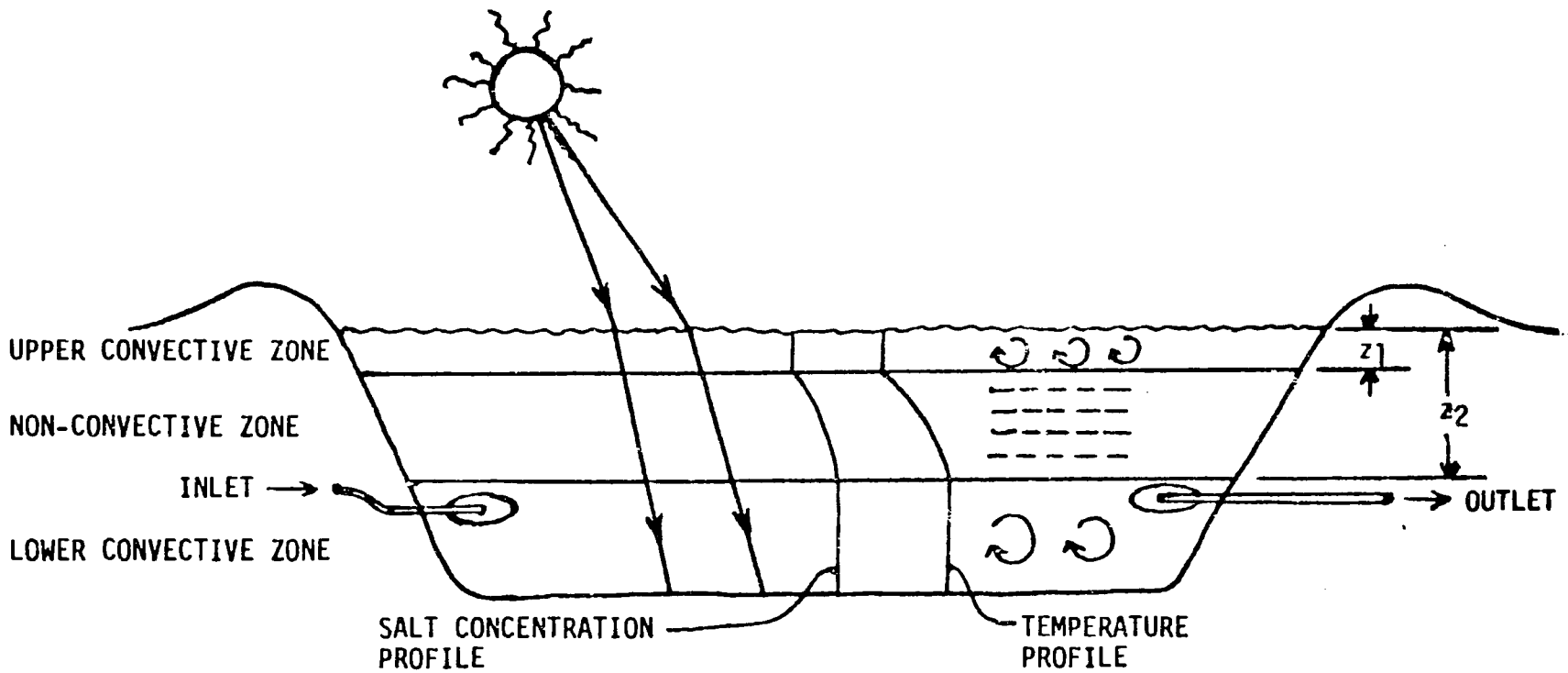

Figure VII-2.1 THREE-ZONE SALT GRADIENT SOLAR POND

(7) The pond is a good collector of diffuse radiation which appears to be an appreciable fraction of the radiation in Cape Verde.

(8) Ponds will be more efficient in low latitudes, such as in Cape Verde, because of weak diurnal temperature cycling. Furthermore, a major disadvantage of ponds in high latitudes - that they cannot be set at their optimum tilt angle - is no problem in Cape Verde where the optimum position is nearly the horizontal.

(9) Heat can be extracted at rates as high as 10 times the average collection rate and it can be drawn at any time desired. This makes it possible to exactly match output to load requirements. Most other forms of solar energy and wind energy do not have this attractive property. Because of it a solar pond electricity system could supply the total electricity needs of a city while wind or photovoltaic power systems could supply only about 20 %.

(10) Solar ponds cannot be tilted or inclined to take advantage of low solar altitudes. However, this is not important at low latitudes such as that of Cape Verde where the horizontal position is nearly correct.

(11) The instantaneous efficiency of a solar pond at lower temperatures is only about half of that of a good flat plate collector. However, 24-hour efficiencies and efficiencies at higher operating temperatures (90°C - 100°C) for large area ponds are expected to be similar to or better than those of large flat plate collector systems. The latter have significant heat losses from the piping and require more pumping power.

(12) Solar ponds cannot generally use waste space, such as roof tops, but need larger areas of level ground.

(13) Small solar ponds are less eficient. They are best for larger sizes perhaps above 100 square meters. They do not appear to be useful in sizes as small as single-family solar hot water heaters.

(14) Solar ponds require an annual water supply of about 2 meters per square meter of pond area and an annual salt supply of about 20 kg per square meter of pond area. The water can be brackish or sea water.

(15) Perhaps the biggest disadvantage of the salt gradient solar pond is the lack of operational experience. Only a few ponds, mostly for research, exist in the world.

Applications in Cape Verde:

The primary applications of salt gradient solar ponds in Cape Verde appear to be for generation of electricity and for desalination. These would, apparently, best be done in conjunction in the same manner as

Table VII - 2.2 Performance and costs for solar pond electrical power generation systems as estimated by Tabor [1] and Burns & Roe [14], adapted to current Cape Verdean conditions.

Item	Tabor	Burns & Roe
Incident radiation (kWh/m^2 year)	2000	2000
Area of pond (m^2)	1,000,000	65,000
Heat produced (kWh/year) (a)	4×10^8	2.6×10^7
Electrical energy produced (kWh/year) (a)	3.2×10^7	2.08×10^6
Maximum power (kW)	5000	275
Cost per area (USD/m^2)	23	31.53
Cost of pond (USD)	23,000,000 (b)	2,050,000 (c)
Cost of turbine, generator, electrical (USD)	7,500,000 (d)	1,442,000 (e)
Life of system (years)	20	20
Charge rate on capital (%)	10	10
<u>Annual costs (USD/year)</u>		
Cost of capital	3,583,000	410,000
Cost of salt; 20 kg/m^2 year at 20 USD/tonne	400,000	26,000
Operation and maintenance	100,000	30,000
Total annual costs	4,083,000	466,000
Cost of heat (USD/MJ)	2.83	4.98
Cost of electricity (USD/kWh)	0.128	0.224

(a) Pond efficiency is taken to be 20 %, electro-turbine efficiency 8 %.

(b) Using Tabor's lined pond at 13 USD/m^2 and adding 10 USD/m^2 for salt.

(c) Reduced cost according to Hull [15].

(d) Using Tabor's higher value, 1500 USD/kW.

(e) Multiplying B&R's 1,012,000 USD by 275/193.

The costs of producing electricity comes out bo be either 12.8 US cents/kWh or 22.4 US cents/kWh. At an exchange rate of 70 to 1 these figures convert to 8.96 CVE/kWh and 15.6 CVE/kWh. The lower value is competitive with electricity produced by diesel generators in Praia. With present prices for diesel fuel, and with a fuel to electricity conversion efficiency of 22 %, as it is for Praia [16], the fuel cost alone is 7.9 CVE per kilowatt hour of electricity produced currently in Praia.

The calculation of annual costs depends strongly on salt costs. If one were to shadow price salt at 10 USD/tonne, and this may be realistic in view of the production capacity for salt on Sal island [17], the cost of electricity would be lowered to 0.103 USD/kWh for the Tabor system.

If both Praia and Mindelo had a 5000 MW solar pond electricity production plant similar to the one analyzed by Tabor, 1,000,000 tonnes of salt would be needed for construction and 40,000 tonnes would be needed annually thereafter for maintenance of the salt gradient. Construction would take place, in modular fashion, over many years so that the 1,000,000 tonnes needed for construction would not be required instantly but rather over a period of many years. Such a viable salt industry would also produce the by-product bittern which can be used as the salt for a solar pond. Presently, bittern has a negative or zero value since it has little or no market value and it is difficult in some cases to dispose of it in an environmentally sound manner. Use of bittern could reduce salt costs to quite a low value but this would probably not occur in Cape Verde until a sizable solar pond - salt production industry was in place.

With respect to costs it is immediately evident that the cost of the turbine-generator and associated equipment is very high. In Tabor's case it is 1500 USD per kW and B&R uses 5243 USD per kW. These are much higher than costs of equivalent electrical generation equipment (diesel electric generators may be bought for several hundred dollars per kW). With widespread use these prices should fall to much lower and more realistic values. Furthermore, experience in pond construction is very limited and this can result in higher cost estimates in order to "play it safe". Thus, one can see substantial possible cost reductions. In fact, Tabor in his 1981 article [1] on the basis of various assumptions estimated electricity production costs ranging from a low of 0.053 USD/kWh to a high of 0.135 USD/kWh*. These costs are more than competitive with the cost of producing electrical energy with diesel or wind generators. However, they can only be attained if the industry grows so that the economies of experience and size can be obtained.

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* With free salt but paying 0.10 USD per cubic meter of water lost by evapocation from the pond surface.

References

1. H. Tabor, "Solar Ponds", Solar Energy, 27, No. 3, p. 181 (1981)

2. H. Bryant, University of New Mexico, Albuquerque, NM. Personal communication.

3. C.E. Nielsen, "Equilibrium Thickness of the Stable Gradient Zone in Solar Ponds", Proc. 1978 Annual Meeting Am. Section of ISES. 2.1, p. 932, Denver (1978).

4. C.E. Nielsen, "Nonconvective Salt Gradient Solar Ponds". Article in Solar Energy Handbook, ed. W.C. Dickinson and P.N. Cheremisinoff, Marcel Dakker, Inc. (1979).

5. J.S. Turner, Bouyancy Effects in Liquids, Cambridge University Press (1973).

6. Y.S. Cha, W.T. Sha, and W.W. Schertz. "Modelling of the Surface Convective Layer of Salt Gradient Solar Ponds", 15th IECEC Meeting, Atlanta, August 9-14 (1981).

7. G. Veronis, J. Mar. Res., 23, p.1 (1965).

8. C.E. Nielsen, "Nonconvecting Salt Gradient Solar Ponds", Nonconvecting Solar Pond Workshop (July 1980). Quoted by Hull, et al. [9].

9. J.R. Hull, Y.S. Cha, W.T. Sha, and W.W. Schertz, Proceedings AS/ISES, June 1-5 (1982). Proceedings to be published by the International Solar Energy Society.

10. C.F. Kooi. "The Steady State Salt Gradient Solar Pond", Solar Energy, 23, p. 37 (1979).

11. H. Tabor. "Large-area Solar Collectors for Power Production", Solar Energy, 7, 189, (1963).

12. H. Tabor and R. Martz, "A Status Report on Solar Pond Project", Solar Energy, 9, p. 177 (1965).

13. R. Peter Fynn and Ted H. Short. "Solar Ponds - A Basic Manual", The Ohio Agricultural Research and Development Center, The Ohio State University, Wooster, Ohio, 44691, U.S.A. (1983).

14. "Engineering Study of Desalination Using Salt Gradient Solar Ponds - Final Report", Burns & Roe Industrial Services Corporation, Paramus, N.J., U.S.A. (1982).

15. J.R. Hull, Memorandum to C. Kooi, Abidjan (1982)

16. S. Blake, "Wind Energy Resources in the Cape Verde Islands", Route 1, Box 93-A, Oskaloosa, Kansas 66066, U.S.A. (1979).

17. Voz di Povo, p. 12, 29 de Abril de 1983, Praia.

3. Desalination and electrical power systems:

In this sectionwe use the experience gained from operation of the Mindelo desalination plant and from construction of the Palmeira (Sal Island) desalination-electricity production plant to estimate costs of desalinated sea water. We also estimate the costs of desalinated brackish water from a small isolated desalination plant. Previously (Section IV) we had determined costs of desalinated water from a simple solar still.

All of these cost estimations allow us to see what place energy from wind machines and solar ponds has in the domain of desalination and electricity production. We recommend immediate steps to introduce wind power and long term steps to introduce solar power via solar ponds.

This subsection consists of parts (a) through (f).

(a) Estimates of Cost of Desalinated Water Based on Experience at the Mindelo Desalination Plant:

Many calculations of the costs of desalinating sea water in Cape Verde have been done. Most of them are design predictions or are somewhat out-dated (and costs have increased dramatically in recent years). Therefore, it is useful to do new cost calculations, especially calculations using operational data from the São Vicente desalination plant.

Lourenço Assis Lopes of ELECTRA, São Vicente, accompanied me on a plant visit on May 10, 1983. We discussed plant operation with plant manager Engineer Sonia Morais who gave us information on fuel consumption, water production and other operational information. Subsequently, Eurico Pascoal Almeida, Director of ELECTRA, and Manuel de Jesus Monteiro, Director of Administration and Finance, ELECTRA, in São Vicente discussed, among other things, the desalination plant operation and gave me financial data concerning it. I will use this data, recognizing that it is not complete enough to do exhaustive cost calculations. However, it will have the useful purpose of giving us some idea of the cost of distilled sea water and allow us to make some guesses of future costs.

Input data:

Cost of plant:	Dutch Contribution	144,000,000 CVE
	Other (including boiler)	139,500,000 CVE
	Total	283,500,000 CVE
Price of fuel oil:	1982	11,850 CVE/tonne
	1983	13,050 CVE/tonne
Consumption of fuel:	1982 (19 tonnes/day x 230 days)	4,370 tonnes
Rated fuel consumption:		20 tonnes/day
Production of water:	1982 (87-90 m^3/hour x 230 days x 24 hours)	496,800 tonnes
Rated production:		100 tonnes/hour
Interest rate:		3 %
Predicted life of plant:		20 years

Current costs per tonne of water as given by ELECTRA (May 1982):

Investment	15.54 CVE/tonne
Fuel	106.14 "
Replacement parts	1.48 "
Salaries	16.03 "
Chemicals	1.48 "
Insurance	0.50 "
Total	141.17 CVE/tonne

Calculations of costs under various assumptions:

A. Capital cost (Dutch contribution only	144,000,000 CVE
Water production (1982)	496,800 tonnes
Plant life	20 years
Interest rate	3 %
Annual payment (on 20 year, 3 % loan of 144,000,000)	9,679,062 CVE
Capital cost per tonne of water	19.48 CVE/tonne

This is not far from that given above in the "Input Data" section. However, it seems reasonable to use the full investment cost, a more realistic interest rate of 10 %, and a plant life of 15 years (the old Mindelo plant is no longer being used, except for one line as a backup, after only 10 years of use and the plant at Santa Maria on Sal island is nearing the end of its useful life after about 10 years of operation).

B. Capital cost:	283,500,000 CVE
Water production (1982)	496,800 tonnes
Plant life	15 years
Interest rate	10 %
Annual payment (on 15 years, 10 % loan of 283,500,000)	37,272,816 CVE
Capital cost per tonne of water	75.03 CVE/tonne

This is over 4 times higher than the figure used by ELECTRA and is probably about what a private company would have to charge.

C. Fuel costs:	
Fuel used in 1982 (19 tonnes/day x 230 days)	4,370 tonnes
Cost (11,850 CVE/tonne x 4370 tonnes)	51,784,500 CVE
Cost per tonne of water (÷ 496,800)	104.24 CVE/tonne

This is almost the same as the fuel cost per tonne of water calculated by ELECTRA ("Input Data" section).

D. Cost of water in 1982:	
Capital cost (from B at 10 %, 15 year life)	75.03 CVE/tonne
Fuel cost (from C)	104.24
Replacement parts, salaries, chemicals, insurance (from "Input Data")	19.49
Total cost per tonne of water at plant gate	198.76 CVE/tonne

If one were to add 20 % for distribution losses and costs, the true cost to the customer would be 238.51 CVE/tonne

E. Cost of water (and electricity) in 1984:

Currently there is 200 kw of electric power that is not used in the plant and can be sold to the electric grid of São Vicente. It is planned to do this as soon as some necessary regulating equipment is installed. We will assume that this can be done and that the plant will operate at full capacity (200 kW and 100 tonnes of water per hour) for 300 days (82 % on full capacity) during 1984. Assume 8 % inflation on fuel, 6 % on everything else. Assume electricity can be sold at the plant gate for 10 CVE/kWh.

Annual payment on capital: (from B)	33,299,304 CVE
Annual cost of fuel: (20 tonnes/day x 300 days x 13,050 CVE/tonne x x 1.08)	84,564,000 CVE
Annual cost of replacement parts, salaries, chemicals, and insurance: [19.49 CVE/tonne x 720,000 tonnes water x 1.06 (inflation)]	14,874,768 CVE
Subtotal:	132,738,372 CVE
Sale of electricity: (200 kW x 24 hr/day x 300 days x 10 CVE/kWh)	-14,400,000 CVE
Total cost of water	118,338,372 CVE
Cost per tonne of water (÷ 720,000 tonnes)	164.36 CVE/tonne

This cost (at the plant gate and before distribution) is lower than the cost (D.) because of higher assumed production (720,000 tonnes of water instead of 496,800) and the sale of electrical energy.

F. Let us build, as a private investment, a new plant, similar to the present plant at Mindelo, in 1984 and commence operation the same year. We will take the cost of the plant to be the cost of the present plant inflated by 6 % per year from 1980 to 1984. This is a cost of building the plant of 283,500,000 x $(1.06)^4$ = 358,000,000 CVE. Then let us do a calculation of the present values of all costs and all benefits. We will use the following input values for this benefit/cost analysis which are based to a large extent on operating experience at São Vicente. All costs are 1984 costs.

Cost of constructing plant:	358,000,000 CVE
Life of plant:	15 years
Major overhaul at year 8: (15 % of plant value)	54,000,000 CVE
Salvage value at year 16: (15 % of plant value)	54,000,000 CVE
Production rates: Electric energy for sale	4800 kWh/day
Desalinated sea water	2400 tonnes/day
Time on-line:	300 days/year
Fuel oil consumption:	20 tonnes/day
Routine replacement parts, salaries, chemicals, insurance:	20,000,000 CVE/year

Fuel oil price (1984):	14,000 CVE/tonne
General inflation rate:	6 %/year
Fuel price inflation rate:	8 %/year
Discount rate:	10 %/year

The present values of the costs are:

Cost of constructing the plant	358,000,000 CVE
Fuel: [6000 tonnes/year x 14,000 CVE/tonne x PV (20,8,10)*]	1,393,361,000
Replacement parts, salaries, etc: [20,000,000 x PV (20, 6, 10)*]	277,338,000
Major overhaul: [54,000,000 x P (8, 6, 10)*]	40,151,000
Salvage value: [54,000,000 x P (16, 6, 10)*]	-29,854,000
Total present value of costs over 20 years life:	2,038,996,000 CVE

We will choose the input values for calculation of the present values of the benefits to be:

Sale price of electrical energy in 1984 at plant gate:	11 CVE/kWh
Sale price of desalinated water in 1984 at plant gate:	164.91 CVE/tonne
Price increase rates of electrical energy and water:	7 %/year
(All other rates as in cost calculation)	

The present values of the benefits are:

Sale of electrical energy: [4800 kWh/day x 300 days x 11 CVE/kWh x PV (20, 7, 10)*]	239,993,000 CVE
Sale of water: [2400 tonnes/day x 300 days x 164.91 CVE/tonne x PV (20, 7, 10)*]	1,799,003,000 CVE
Totals of present values of benefits:	2,038,996,000 CVE

Under all of the above assumptions and with the given inputs one would have to operate at nominal capacity for 300 days per year and sell electrical energy and desalinated sea water by the following price schedule :

Price of electrical energy at plant gate and increasing at 7 % per year.	11 CVE/kWh in 1984
Price of water at plant gate and increasing at 7 % per year	165 CVE/tonne, in 1984

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* PV (N, I, R) and P(N, I, R) are present value factors defined in Appendix C.

Summary of desalination in Mindelo:

One can see that, under realistic choices of inflation and discount rates, the price of desalinated sea water is at least 150 CVE per tonne before distribution, and it will probably have to increase at about 7 % per year. Of course, a sensitivity analysis, in which the inflation and discount rates are changed, should be done. One should also observe that the predominate cost over the life of the plant is fuel. It is nearly 70 % of the total so that its inflation rate is really the big unknown (we know its price today). An 8 % inflation rate in CVE's does not seem unreasonable but it could be smaller and it could be much larger. Therefore, alternate energy sources such as wind, coal, and solar energy should be considered.

(b) Cost of Desalinated Water Based on Experience at the Palmeira Desalination Plant:

This plant has just begun to operate (early 1983) so that there is as yet no operating experience. However, we know the cost of the plant and its basic design parameters. They are:

Installed cost including 1 MW of diesel generators, complete feedwater intake and treatment system, reservoir and buildings: 7,000,000 USD

Rated output	660 tonne water/day 1 MW electric power

If we assume that the plant runs at 90 % of capacity, then it will produce 7884 MWh of electricity and 216810 tonnes of water. If water production requires 6 kWh of electrical energy per tonne of water then the plant will have the following products for sale

For sale at 90 % plant capacity:	
Electrical energy	6,583,000 kWh
Desalinated water	216,810 tonnes

We will assume a 20 year plant life and a 10 % interest rate. Although Flour Corporation [1] assumes that annual costs of operation, maintenance and membrane replacement are 13 % of plant cost for a sea water RO plant we will assume them to be only 4 %. Fuel costs will be computed on the basis of 4.5 MWh of electricity produced for each tonne of fuel consumed and fuel will cost 350 USD per tonne.

Using these figures the annual costs are:

Cost of capital [7,000,000 PV(20,0,0.1)]*	822,500 USD
Cost of operation, maintenance, and membrane replacement (7,000,000 x 0.04)	280,000 USD
Cost of fuel (7884 x 350/4.5)	613,200 USD
Total annual costs	1,715,700 USD
Total annual costs in CVE (at 70 CVE = 1 USD)	120,100,000 CVE

We will assume that electricity can be sold at the plant gate for 9 CVE/kWh** and that water will be priced at the plant gate so as to make annual income equal annual costs. This gives

Sales of electricity (6,583,000 x 9)	59,247,000 CVE
Sales of water (216,810 x 281)	60,853,000 CVE
Total annual sales	120,100,000 CVE

The sale price of water will have to be 281 CVE (4 USD) per tonne in order to break even.

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* See Appendix C for definition of the present value factor PV(N,I,R).

** Sale price of electricity to private residences in Praia is 10.65 CVE/kWh.

It will be higher than this if the plant factor drops below 90 %, if the costs of operation, maintenance, chemicals and membrane replacement are higher than 4 % of plant capital costs and if diesel fuel prices rise above 350 USD/tonne.

One can, of course, allocate the sales prices of water and electricity differently. For example, if electricity were sold at 11 CVE/kWh, then the sale price of water could be reduced to 220 CVE/tonne. Compare this to the plant gate sale price calculated for the Mindelo Desalination Plant: 11 CVE/kWh for electricity and 165 CVE/tonne for water.

(c) Stand-alone P.C. brackish water desalinator:

Brackish water of 200-5000 mg/l dissolved solids is found in some acquifers in Cape Verde. Since desalination of brackish water requires less energy than desalination of sea water one might be able to obtain cheap fresh water this way. In order to take advantage of this difference one cannot use an evaporation method of desalination but must use reverse osmosis (RO) or electrodialyses (ED) because the energy required with these methods decreases with decreasing salt content. We will consider an RO plant of about 100 m^3/day capacity and assume it to be located in a place such as Terra Boa north of Preguiça on Sal Island.*

In order to develop accurate cost data and determine the cost of fresh water a complete engineering study and design is needed. While awaiting such a study we can make some estimates of costs based on similar operating desalination plants and on other engineering estimates, notably those by Flour Corporation as presented in "The U.S.A.I.D. Desalination Manual" [1] .

We will consider a diesel driven system and a diesel-wind driven system. In order to estimate the cost of a diesel driven system we will estimate from Fig. 8-1 of the Desalination Manual [1] that the capital cost of a brackish water RO system of 100 m^3/day capacity will be between 80,000 and 100,000 USD. However, that is a 1978 estimate and it is for a basic system installed in the U.S.A.** We must therefore allow for inflation, overseas construction, addition of a diesel generator, reservoirs, more extensive feedwater treatment, shipping, and a more extensive feedwater and waste water system. We will assume an average annual inflation rate of 8 % from 1978 to 1984 which multiplies costs by a factor of 1.6. The cost range then becomes 128,000 to 160,000 USD.

In order to allow for the other factors mentioned above we can use the experience gained on the Palmeira RO plant which was built mainly in 1982. The Desalination Manual says it should have cost, allowing for inflation from 1978 to 1982, between 1,400,000 and 2,200,000 USD. Since its actual cost was 7,000,000 USD the multiplication factor for all of the differences listed in the proceeding paragraph falls between 3.2

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* We will assume that there is sufficient brackish water in the acquifer to supply a desalinator of 100 m^3/day capacity.

** The warning which accompanies Fig. 8-1 from which the costs are taken is reproduced here.

"1. Caution should be exercised when using these data.

2. These costs are computed for basic desalination facilities in the USA. These costs include no storage capacity and allow for only fundamental feedwater development and brine disposal. If storage capacity is added and/or more complex feedwater or brine facilities are required, overall project costs can significantly increase. This is especially true with brackish water facilities. Construction in locations outside the USA can also add to the overall cost. Actual costs of up to 300 % (or more) of those shown on this figure (especially at lower capacities) would not be unusual for projects in many developing areas.

and 5. Therefore our 100 m^3/day plant should cost between 400,000 and 800,000 USD.

At a location such as Terra Boa consideration must be given to brine disposal. The quantity of brine can range from 10 to 50 % of the fresh water produced. Therefore one would have to dispose of 10 to 50 cubic meters of brine per day. A lined settling basin of 200 to 10,000 square meters would be needed at a cost of 30,000 to 150,000 USD.

Alternatively the brine could be piped to the sea. We will for simplicity assume that either piping to the sea or disposal in a pond can be done for a capital cost of 50,000 USD.

From the experience of the 100 m^3/day RO plant in Bahia Asuncion [page 9-25 of ref.1] we find a specific diesel fuel consumption of 2.75 liters per cubic meter of water produced and a plant factor of 65 %. We will choose operating costs including chemicals and membrane replacement, but not diesel fuel, to be 10 % of the capital cost although Flour [p.8-11 ref. 1] states that they are 25 % of the capital cost for a brackish water RO plant. The price of diesel fuel is presently 21 CVE/l = 0.30 USD/l. The life of the system will be 20 years even though the older desalination plants on Sal and São Vicente only operated about 10 years. The discount rate will be 10 %.

With these figures we can compute the annual water production and annual costs to be

Water produced (65 % plant factor)	23,725 m3
Capital cost (450,000 USD x 0.1175)	52,875 USD
Fuel cost (2.75 x 23,725 x 0.30)	19,573 USD
Operation and Maintenance and Membrane Replacement	45,000 USD
Total Annual Costs	117,448 USD
Cost of water	4.95 USD/m3

In this calculation the lowest cost of the plant, 400,000 USD plus 50,000 USD for brine disposal facilities, was used. If the high value 850,000 USD were used, and all other costs were the same, the cost of water would be 6.93 USD/m^3.

If we used the lowest capital cost (450,000 USD) and a 90 % plant factor instead of 65 %, the cost of water would be 3.80 USD/m^3.

Let us install a windmill which will be able to supply one half of the energy used by the plant. Assume 90 % plant capacity and a capital cost of 450,000 USD, without the windmill, and an electric energy to diesel fuel conversion ratio of 3 kWh/l. Then the windmill would have to produce 136,000 kWh/year. Such a windmill could be installed with electrical equipment to properly accord with the diesel and desalination plant for 70,000 USD. The total capital cost would be increased to 520,000 USD but diesel fuel costs would be halved. Assume that the windmill would not increase operation and maintenance costs. The cost

of water would then be 3.64 USD/m^3*.

The addition of a windmill to supply one half of the energy lowered the water cost from 3.80 to 3.64 USD/m^3. The fraction of energy assigned to a windmill cannot be increased much more without decreasing the plant factor or over-sizing the windmill. Both of these things increase the cost of product water. In fact it is doubtful if a 70,000 USD windmill can perform as we have assumed here, namely, supply half the energy while maintaining a 90 % plant factor.

These calculations suggest that desalinated brackish water from a 100 m^3/day RO plant will cost well over 3.00 USD/m^3 and probably closer to 6.00 USD/m^3. Using wind energy doesn't help much. In fact, if diesel fuel were free the cost of water would decrease only to 3.00 USD/kWh for this small isolated system.

Electrodialysis should also be considered since its energy consumption (and cost of water) may be slightly lower than RO [see ref. 1, Fig. 8.2]. Furthermore start-up and intermittent operation are easier. This makes it more suitable than RO for wind power which can be an unsteady power source.

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* To convert to CVE use 70 CVE = 1 USD.

(d) Full and partial utilization of renewable and fuel-consuming energy systems:

It is important to recognize that renewable energy systems must be as fully utilized as possible in order to produce the lowest cost energy. This is in sharp contrast to fuel-consuming energy systems which can be idle without too much of a penalty.

The reason a diesel generator can be idle with only a small penalty and a wind electric generator cannot is because the major cost of running the diesel is the cost of the fuel while the major cost of running a wind electric generator is the cost of the investment. The former expense stops when the generator is idle; the latter expense continues during idle periods. To produce inexpensive electricity it is very important that the wind generator be fully used and it is less important that the diesel generator be fully used.

To illustrate this we will compare two systems that produce equal amounts of energy which we will choose to be 200,000 kWh per year. The first will be a diesel generator whose cost is 700,000 CVE and whose specific fuel consumption is 0.280 liter/kWh. It will be a 46 kW unit operating 12 hours per day. The wind machine, sized to produce the required annual energy at the chosen location, will cost 7,000,000 CVE. The cost of fuel will be 21 CVE/l, the life of both systems 20 years, and the discount rate 10 %. Operation and maintenance costs will be taken to be much smaller than other costs and therefore neglected without seriously affecting total costs. Furthermore, lower utilization should result in longer life, greater than 20 years, but this factor has also been neglected since it is probably small and would apply to both systems and therefore not strongly affect comparative results.

The annual cash flows are

Diesel generator

Cost of capital:	700,000 x 0.1175	82,000 CVE
Cost of fuel:	200,000 x 0.280 x 21	1,176,000 CVE
Cost per kWh:	1,996,000/200,000	6.29 CVE/kWh

Wind generator

Cost of capital:	7,000,000 x 0.1175	823,000 CVE
Cost per kWh:	823,000/200,000	4.11 CVE/kWh

When the systems are utilized fully (at the design capacity) the wind generated electricity is less expensive. If we were to utilize them at 40 % of design capacity and produce 80,000 kWh/year of electricity the costs per kWh would be 6.91 CVE/kWh for the diesel and 10.29 CVE/kWh for the wind generator. The wind machine would be more expensive than the diesel instead of less as at full capacity.

The general expression* for energy costs from a fueled system is

$$\text{Cost of energy for fueled systems} = \frac{\text{fixed costs} + \text{fuel costs} \times f}{f}$$

where f is the fraction of utilization of design capacity. The general expression for a non-fueled (renewable) system is

$$\text{Cost of energy for renewable systems} = \frac{\text{fixed costs}}{f}$$

These two equations are shown on Figure VII-3.1 for the costs of the diesel and wind example above. The importance of fully utilizing the capacity of renewable energy systems is evident. For low percentage utilization wind energy, and most renewable energies, become prohibitively expensive while fueled systems are not strongly penalized by low utilization.

This same principle applies to any large capital investment, especially for desalination plants which are quite expensive. They must be used as near to design capacity as possible. A reverse osmosis plant driven by a renewable energy source that could only operate the plant 45 % of the time would probably not compete with a plant powered by diesel, which could operate it at 90 % of design capacity, unless the renewable energy were produced at a very low cost.

This militates against isolated, one-purpose, renewable energy systems. Both the consumer and the renewable energy system dictate plant shutdown. For example, an isolated wind driven desalination plant for irrigation would be limited to operation at perhaps 50 % of capacity by irrigation demands and to 50 % by lack of wind. The result is 25 % utilization of the total plant. Compared to, say, operation at 75 % of design capacity for a diesel-driven integrated system, the isolated renewable system is at a basic 3 to 1 disadvantage and product costs could be about 3 times higher.

If power demand coincided with wind speed the wind machine could be utilized at a high percentage of design capacity and its energy would be the cheapest. On the other hand if demand was poorly correlated with wind speed low utilization could occur and its energy could be the most expensive.

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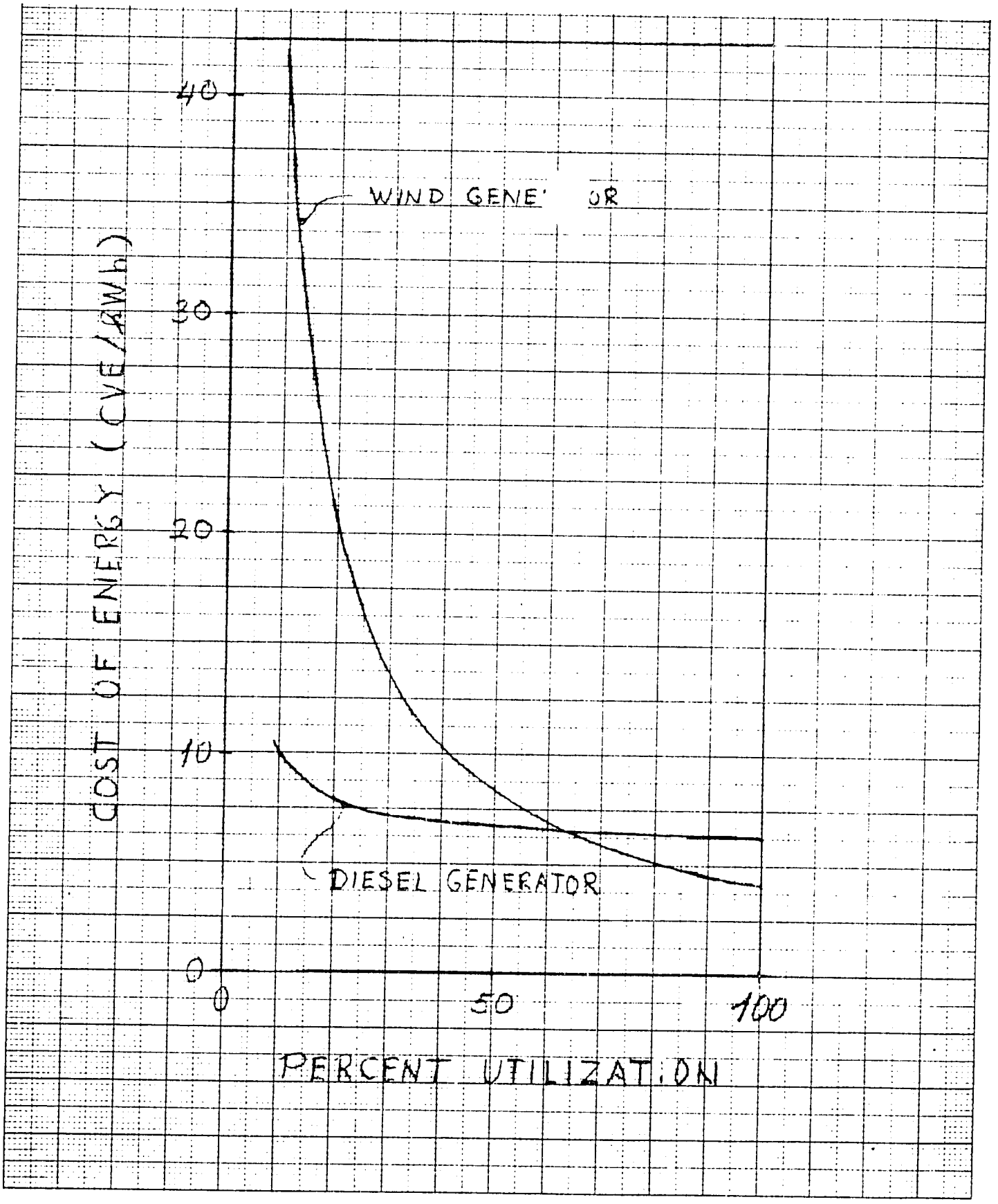
* Neglecting operation and maintenance costs and the effect of utilization on lifetime of the system.

Fig. VII-5.1. Cost of producing electrical energy as a function of percent of design capacity utilized. For a renewable energy system (wind) and a fueled energy system (diesel).



(e) Renewable Energies for Desalination and Electricity:

We have seen that the costs of producing desalinated water are very high and that, in addition high capital costs, fuel costs are a major contributor to these high costs. Furthermore, the fuel is imported, must be paid for in hard currency, and its price has been steadily increasing over the last few years (see Section V). Therefore, it would be advisable to substitute local, renewable energy sources for petroleum fuels. Imports could be reduced, hard currency saved, relief from escalating oil prices obtained, local industry and labor would be supported, and the cost of the product, desalinated water and electricity, could possibly be stabilized.

We have also seen that it is important that expensive renewable energy or desalination systems be used as much as possible, i.e., the percent utilization or plant factor should be high. This is hard to do in isolated systems having only one product or one user. It is even more difficult when a solar or wind energy system is part of the system since these energy sources are intermittent and, if there is no energy storage, practically guarantee that the system will function less than fifty percent of the time. It is much easier to utilize expensive systems, or parts of systems, fully if it is a larger multi-source, multi-user, multi-product system. This is why a system supplying both electricity and water to all of Sal island is preferred to a number of small isolated systems that would supply water or electricity to smaller user groups. It could be feasible to use wind or solar pond energy in such a system even though it might not be feasible to use them in a smaller-isolated system.

The renewable energies technologies that we have discussed which are appropriate for large desalinated water and electricity production are wind machines and solar ponds. Photovoltaics, presently too expensive, should enter the competition for large system applications in the future.

It has been shown earlier that wind energy may be somewhat less expensive than solar pond energy.* Because of the lack of operational experience with ponds their real costs are not well known. They could furnish energy as cheaply or more cheaply than wind. As explained earlier in this section solar ponds have a very attractive quality which wind machines lack. They can furnish power to exactly satisfy the demand. Peak powers ten times the average power are available. This means that whereas wind energy is generally thought to be able to furnish up to 20 % of the energy for an electric power system, pond power can furnish 100 %. Inclusion of desalination in a system may increase the possible wind fraction somewhat.

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* For Cape Verde. In a country with lower wind speeds, wind energy would be more expensive.

In view of these considerations, and previous discussions of costs and the technical properties of wind machines and solar ponds, it appears that programs to integrate wind machines and solar ponds into electricity and desalination systems in Cape Verde should be undertaken.

(f) Summary of costs of desalinated water:

Various values have been calculated in this report for the cost of desalinated water in Cape Verde. The results in CVE/m^3 are summarized below.

	Lowest	Probable
Simple solar still (VI-2)	320	870
Mindelo desalination plant (VII-3)	141	165
Palmeira desalination plant (VII-3)	220	281
Small brackish water RO plant (VII-3)	266	347

These costs reflect shipping and construction costs that are much higher than those in, for example, the United States. One can, of course, choose lower discount rates (10 % is usually used in this report) and calculate lower costs. There are also other choices one can make to calculate lower costs but even with the most optimistic and unrealistic assumptions it doesn't seem possible to get below about 140 CVE/m^3 (2 USD/m^2). In this respect it should be noted that the cost of water from older desalination plants in Cape Verde has been estimated to cost well over 10 USD/m^3 (700 CVE/m^3).

(h) References:

1. "The U.S.A.I.D. Desalination Manual", United States Agency for International Development, Washington, DC 26523 U.S.A. (1980).

4. Water pumping:

A number of calculations of the costs of pumped water in Cape Verde have been made in past years. These have included pumping by mechanically connected and electrically connected wind machines, diesel engines, photovoltaic pumps, solar thermodynamic pumps and perhaps other techniques. Here we wish to make an up-dated comparison between three promising techniques - mechanically coupled wind, diesel and photovoltaic pumps under similar conditions. The objective of this comparison is to see roughly under what conditions each of these pumps will be cost competitive in terms of the pumping cost per tonne of water. In particular we would like to see to what level photovoltaic system prices must fall in order for them to be cost competitive.

Blake [1] compared diesel and wind water pumping in 1978-79. He concluded that wind water pumping was cost competitive with diesel pumping at average wind speeds above 6.7 m/s. However, he compared a larger diesel pump to a smaller wind pump (annual quantities pumped in the ratio 9 to 1) which favors the larger pump. Furthermore, fuel prices have doubled since 1978-79. Therefore one would expect this break-even average wind speed to be lower and we will find in the following analysis that it is indeed lower.

We will choose a location in which we would expect photovoltaic pumping to first become cost-competitive. This would be in a sunny ribeira where wind speeds are lower than on the achada's and ridges. We will use the basic analysis of Beurskens [2] for the diesel and wind pumps with recent cost data from D.E.R. and some changes introduced by the author. The photovoltaic pump input data will be actual measured performance data from Sudan and Mali [3] translated to the almost identical Cape Verdean solar environment.

Photovoltaic pumping in a ribeira:

Currently photovoltaic pumps in the 1 kW peak power range are being installed in West Africa for about 30 USD/peak watt. Since solar panels can be bought at the factory for about 10 USD per peak watt one must ascribe about 20 USD per peak watt to BOS (Balance of System) costs, shipping, fees, etc. Measurements in Mali and Sudan show that at least two types of photovoltaic pumps, Guinard and ARCO, have overall sun-to-pumped-water efficiencies of 2 to 3 % over a range of insolation of about 5 to 8 kWh/m^2 day [3]. Literature from another manufacturer, Solar Power-SOFRETES [4], claims an overall efficiency of 3 % at an insolation of 5.4 kWh/m^2 day. They also state that the solar cell area for 1 kW peak power rating is 9.38 square meters. This information allows us to calculate an annual water output and its cost in a Cape Verdean environment.

From Section III we can determine an average annual insolation at Praia of 2070 kWh/m^2 for the years 1961 through 1970 for example. This and the information above allows us to calculate the amount of

water pumped a vertical height of 20 meters by a pump rated at 1500 watts peak

choosing 2 % overall efficiency	10,690 m^3
choosing 3 % overall efficiency	16,040 m^3

The 2 % value is probably more realistic since we suspect the measured insolation values to be slightly high and because using the yearly average insolation does not account for the lower system efficiency on days of weak insolation [see Fig. 8, p. 164, ref.3]. On the other hand one would expect system efficiencies to increase as more experience is gained and systems are optimized. Therefore the 3 % value may be realistic for estimates of performance in the future.

The cost of photovoltaic pumped water over a vertical distance of 20 meters is, assuming a 20 year life and 10 % interest rate,

Annual cost of capital (45,000 x 0.1175 x 70)	370,000 CVE
Annual maintenance and operation cost	10,000 CVE
Operator guard	36,000 CVE
Total annual cost	416,000 CVE
Cost of pumping water 20 meters (416,000/16,000)	26.0 CVE/m^3

As usual the conversion rate used is 70 CVE = 1 USD. This calculation can be repeated for system costs of 20, 10, 5, and 3 USD per peak watt to get the following cost table.

Price of installed system per peak watt	Cost of pumped water
30 USD/peak watt	26.00 CVE/m^3
20 "	18.29 "
10 "	10.58 "
5 "	6.73 "
3 "	5.19 "

If we choose the lower bound of the overall efficiency range these values would all be multiplied by 3/2. However, in light of the very elementary stage of development of photovoltaic pumps one must expect efficiencies to increase rapidly as solar cells become more efficient and better cell to pump matching is attained. Therefore the "3 %" table above should be quite realistic if not conservative.

Reservoir costs are not included. If we use Beurskens annual costs for water storage which are 2.09 CVE/m^3 for two days of storage then the cost of pumped water will be

Price of installed system per peak watt	Cost of pumped water with storage
30 USD/peak watt	28.09 CVE/m3
20 "	20.38 "
10 "	12.67 "
5 "	8.82 "
3 "	7.28 "

Commercial windmill pumping in a ribeira:

Beurskens [2], p.H-4 has given a cost analysis of a 3.5 meter windmill pumping water in a ribeira. The mean wind speed was taken to 4.7 m/s. This work was done in 1981 and is in need of up-dating which we shall do using the latest information on costs communicated by Niko Pieterse of D.E.R.

In addition to the latest cost information we shall assume a lifetime of 20 years instead of 30 years, as Beurskens assumed, since the latter appears to us to be too high in view of past records of windmills in West Africa especially in a marine environment. There are badly rusted relics of steel windmills in Cape Verde to testify to this. The costs of a Dempster 12' (3.66 m) windmill as given by Pieterse are:

Installed cost including purchase, shipping piping and labor: 327,515 CVE	
Annual cost of installed system for interest rate of 10 % and 20 yr/life:	38,483 CVE
Maintenance	12,257 "
Repairs	3,154 "
Operator guard	36,000 "
Total annual cost	89,894 CVE

Beurskens gives annual water production over a 20 meter head as 16,000 m3. Therefore the cost of pumped water is:

Cost of pumped water **5.62 CVE/m3**

This does not include reservoir costs. If we use Beursken's annual cost for storage of 2.09 CVE/m3 this becomes

Cost of pumped water with storage **7.71 CVE/m3**

Recent "snapshot" measurements of the pumped water production of six Demptster 8' (2.44 m) windmills by D.E.R. indicates that the annual quantity pumped by a 12' Dempster may be considerably less than 16,000 m3. The average, converted from 8' to 12' by the factor $(12/8)^2$, was about 10,000 m3/year. Furthermore some of these windmills were on plateaux where wind speeds are greater than in ribeiras. Since these are very preliminary measurements they cannot be used with confidence. However

they indicate that the cost per cubic meter of water could be 1.6 times more than calculated above or 10.31 CVE/m^3 (allowing for less storage).

Diesel pumping in a ribeira:

Beurskins has also calculated the cost of diesel powered water pumping in a ribeira. He finds that the cost of pumping 16,000 m3 of water annually over a 20 meter head costs 3.31 CVE/m^3. We will update his cost data from 1981 to 1984 by an inflation factor of 6 % per year or $(1.06)^3 = 1.191$. However, in keeping with current folklore on diesel lifetime in West Africa we will take the diesel pump lifetime to be 5 years instead of 10 years. Fuel costs will be 21 CVE/l for early 1984 (about the current price). We have also added an operator-guard at 36,000 CVE per year. With these changes Beurskens's cost table on page H-8 [ref.2] becomes

Investments	166,742 CVE
Installation	14,888 "
Interest: 10 %	
Service life: 5 years	
Annual capital costs	47,974 "
Maintenance per year	17,865 "
Operator-guard	36,000 "
Fuel costs at 21 CVE/l	18,396 "
Total annual costs	120,175 CVE
Cost of pumped water (120,175/16,000)	7.51 CVE/m^3

This does not include the cost of a reservoir but for a diesel system a very small reservoir (or none) may suffice.

Summary of water pumping costs:

The foregoing analyses yields costs of water pumping in a ribeira as follows.

Parameters:

16,000 m^3 of water pumped annually to a head of 20 meters
Insolation: 2070 kWh/m^2 year
Average wind speed: 4.7 m/s
Price of diesel fuel: 21 CVE/l

Costs of pumped water:

Diesel (no storage)	7.5 CVE/m^3
Wind (2 day storage)	7.7 CVE/m3
Photovoltaic (2 day storage)	28.09 CVE/m3

If photovoltaic systems costs decrease as predicted the costs will be, including 2 day storage:

. at 30 USD/peak watt	28.09 CVE/m^2
. at 20 USD/peak watt	20.38 CVE/m^2
. at 10 USD/peak watt	12.67 "
. " 5 "	8.82 "
. " 3 "	7.28 "

We see that in a ribeira at this wind speed and volume per day that wind and diesel are about equally costly and photovoltaic is 3.5 times more expensive. The cost of photovoltaic systems will have to fall below 10 USD/peak watt to compete with wind and diesel in this size range, wind, and insolation regime, and at present diesel fuel costs.

We see that systems this small cannot afford a full-time operator-guardian and that water storage costs are too high.

This analysis does not show us what happens for variations in some of the parameters but from other analyses we can point out the following.
(a) As pump sizes become smaller and water volume decreases photovoltaics become relatively more cost-effective.
(b) As diesel fuel becomes more expensive diesel pumping becomes relativemente less cost-competitive.
(c) As average wind speeds decrease from 4.7 m/s wind pumping rapidly becomes too expensive. Conversely it rapidly becomes the most cost-effective as wind speeds increase. In particular, since the average wind speed of 4.7 m/s was postulated for windward directed ribeiras one would expect lower average wind speeds in many ribeiras not oriented in this direction. In such locations wind pumping would be less cost-effective than diesel and perhaps even than photovoltaic pumps at their current high cost.

References:

1. Steve Blake, "Wind Energy Resources in the Cape Verde Islands", Route 1, Box 93-A, Oskaloosa, Kansas 66066, USA (1979).

2. H.J.M. Beurskens, "Wind energy for water pumping in Cape Verde", S.W.D., P.O. Box 85, Amersfoort, The Netherlands (1981).

3. "Small-scale solar powered irrigation pumping systems, Phase I, Project Report", Sir William Halcrow and Partners and I.T.D.G., London. (1981).

3. Jacques Eilard, Solar Power Corporation, Cedex 31 - 92098 PARIS LA DEFENSE - FRANCE (1982).

5. Small rural electrical systems:

The expression "small rural electrical systems" will be taken to refer to units of 25 to 500 watts peak power at locations which cannot economically be supplied with power from a larger system or electrical distribution system. Since small scale remote electricity is not cheap, there must also be a real need such as refrigeration of vaccines or medicines, communications, or lighting of a dispensary. Let us consider such a remote location which requires 1.4 kWh per day of electrical energy.

Let us consider a small gasoline driven generator, a photovoltaic generator and a wind generator. The location will be on a plateau or other good wind area. All of the systems will include batteries for storage of 5 kWh of electricity, enough for 3.6 days if full power is used. This includes the gasoline generator since it cannot be economically started whenever a load (light, refrigerator) requires power. Furthermore, fuel supplies are unreliable, and the machine itself will be out of action occasionally for maintenance and repair. In the following description of these three systems the costs we use include shipping and installation. The ratio CVE/USD is taken to be 70.

Description of systems:

Gasoline generator: A unit of 300 to 500 watts with five batteries of 1 kWh storage capacity each and controls. The battery is 150 USD/kWh. The cost of motor-generator, controls and fuel storage is 35,000 CVE. Gasoline costs at the site are 26 CVE/l. Consumption is 0.5 l per kWh produced (includes battery losses). The motor generator must be replaced every five years, the batteries every 10 years.

Photovoltaic system: The generator consists of ten 35 watt (peak) panels with mountings, connections and controls. Batteries are the same as for the gasoline system. The generator will produce 1.4 kWh per day in Cape Verde except in cloudy mountainous regions. It's life is 20 years. System cost without batteries is 20 USD per peak watt or 7000 USD.

Wind system: The generator is a (approximately) 350 W unit costing 1500 USD with controls, connections, and tower. It's life is 20 years. The batteries are the same as for the other systems.

All of these systems will supply 1.4 kWh of electrical energy per day allowing for battery inefficiencies and occasional down time of up to 3.5 days. They must, of course, be located where there is a supply of gasoline, adequate insolation, and adequate wind for the three systems repectively.

In making comparative cost calculations, we will choose an operational period of 20 years. During this period the gasoline generator must be

Windmill system

Windmill purchase: 1500 USD x 70 CVE/USD	105,000 CVE
Batteries: $52{,}500 \left[1 + \left(\frac{1.07}{1.10}\right)^{10}\right]$	92,000 CVE
Labor: $100 \frac{\text{hrs}}{\text{year}} \times 20 \frac{\text{CVE}}{\text{hr}}$	2.000 CVE
Present value of all costs:	199,000 CVE
Average cost of energy: 199,000/10,220	19.5 CVE/kWh

These calculations will be repeated with fuel inflation rates of 5 % and 7 % above general inflation and for a photovoltaic system cost of 10 and 5 USD per peak watt. Battery costs remain the same. Assembling all of these results we have:

System	Cost of electricity
Gasoline: 3 % fuel inflation rate	34.2 CVE/kWh
" : 5 % "	37.1 "
" : 7 % "	39.6 "
Photovoltaic: 20 USD/peak watt	57.0 "
" : 10 USD/peak watt	33.1 "
" : 5 USD/peak watt	21.1 "
Windmill:	19.5 "

The windmill is the most attractive financially (However, it may not be in ribeiras or valleys that do not flow north-eastward to the sea). This is not generally true in tropical regions between about +20 and -20 degrees of latitude. Except for some islands, coastal regions and elevated areas winds are generally too weak and photovoltaic or gasoline (or diesel) systems are more cost effective.

For very small systems (one or two 35 watt photovoltaic panels) the photovoltaic systems are frequently favored because competitive systems are either not available or have other disadvantages. Table VII-6.1 lists some properties. A system may be chosen for reasons other than cost per kWh of electricity produced.

We have not analyzed the probability of being without power because of extended periods of calm or cloudiness. A wind or photovoltaic generator which would not produce power for a medical refrigerator for extended periods would probably not be acceptable. It should be noted that fuel supply problems also can occur in remote areas and wind or solar may be less subject to interruption.

Table VII-6.1. Some properties of three small electric energy producing systems for remote areas.

System \ Property	Initial price	Need for batteries	Lifetime	Costs & personnel for maintenance & operation	Cost of fuel	Reliability	Cost of producing electricity
Small photovoltaic generators	very high	yes	long	very low	0	very high	Except for very small systems cost is highest. Predicted large cost decreases.
Small wind generators	high	yes	long	low	0	high	Least expensive in good wind regimes.
Small gasoline or diesel driven generators	low	yes, for small loads with continuous on-off demand characteristics	short	high	high	low for remote regions & small units	Intermediate cost, not available or competitive for very small units. Sensitive to fuel price inflation.

6. Improved stoves and cooking methods:

Although we know of no through study of the subject, it is generally perceived that fuel for cooking is scarce and expensive and that collection of wood, brush, and agricultural residues is contributing to land degradation. If fuel is collected much labor and time must be expended. If it is purchased the expense constitutes a significant part of the cost of a meal.

During a visit in July, a household in Ribeira de Santa Cruz reported that it took 1 1/2 to 3 hours to collect wood for 3 days and that a bundle of wood (appeared to be 80 cm long by 30 cm in diameter) cost 140 CVE if purchased.** A second household in the same ribeira reported that fuel collection took one half day every three days. This household also used kerosene for cooking. A meal of cachupa for this five-person family cost:

for	kerosene	1 liter	25 CVE
"	beans	1/2 "	35 "
"	corn	1 "	12 "
"	oil	-	30 "
Total cost			102 CVE

The fuel comprises one fourth of the cost of the meal.

A family in Ribeira dos Saltos reported that 2 to 3 children spent 2 to 8 hours per day gathering fuel. They reported that a bundle of wood cost 100 to 200 CVE and that one bundle cooks one pot of cachupa.

The fuels were varied: cassava wood, acacia, coconut, thorny brush of various kinds, and much of this included roots. For these fuels the three-stone cooking method was used.

Obviously such a brief survey is suggestive only. The sample size is too small and the reported figures vary widely. However, in agreement with other people who have looked at the cooking fuel situation in Cape Verde [1,2], we conclude that obtaining cooking fuels is both expensive and time consuming. Furthermore, leaving organic matter, especially roots, on the land would assist in prevent erosion and add needed organic matter to the soil.

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* This will be taken to include distillation for production of grog.

** The purchased wood must be higher quality and the gathered fuel lower quality since three days of fuelwood is several bundles, and 1 1/2 to 3 hours to collect fuel worth several times 140 CVE would imply an income from wood gathering many times higher than normal daily wages (70-80 CVE).

To alleviate the situation one could (1) use substitute fuels (2) plant trees to increase the supply of fuel and (3)* increase the efficiency of the cooking process. The government is already carrying out a program of substitution by making kerosene available and by subsidizing bottled gas. There are also programs for use of biogas as a substitute fuel, and coal would be less expensive and not as subject to price increases as petroleum. The government is also carrying out extensive tree planting. However, there is no activity directed toward improving the efficiency of cooking and it is there that we propose activity.

The principal approach that has been used for increasing cooking efficiency has been the design, construction, testing and diffusion of more efficient cooking stoves. There are at least two types that merit attention in the Cape Verdean context. The first is the low-mass fired-clay stove being developed at Ouagadougou [3]. Excellent efficiency improvements have been obtained in laboratory tests. Compared to the traditional three stone method which can be 8-15 % efficient these stoves have efficiencies around 35 %. Therefore, all other things being equal, one can cook 2 to 4 times as much with a given quantity of fuel. They are light, portable, durable and inexpensive.

A second type deserving attention is the massive chimneyless stone stove that is being developed in Lesotho [4]. Although it will probably be less efficient than the low-mass fired-clay stove [3] it has the advantage that it can be constructed from readily available material by techniques which are familiar to Cape Verdeans.

Other techniques for decreasing fuel consumption besides improved stoves are available. Two that deserve attention are pressure cookers and insolated boxes or "hay boxes". Because temperatures in a pressure cooker are higher (above 100°C) food cooks more rapidly and the fire need not be maintained as long. However, they are expensive, must presently be imported, and people generally don't know how to use them (and perhaps don't trust them).

The second item is simply an insulated container in which a hot pot containing cooking food can be placed. It is well enough insulated to keep the pot and its contents at cooking temperatures for perhaps 1/2 hour. That means 1/2 hour of cooking with no fuel consumption. For example rice can be brought to 100°C in about 10 minutes then put into the "hay box" to complete its cooking while the fire is used to prepare a sauce. This requires one fire instead of two.

We have not seriously considered solar cookers because of various problems that apparently have not yet been solved. The problems are combinations of cost, amount of attention required, stability, life of cooker,

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* Efficiency is defined in terms of specific test procedures. See ref. 3 for reference to stove testing procedures.

time at which cooking must be done, improper temperature. It doesn't seem that all of these problems have been solved for a specific solar cooker. A recent experience in Lesotho illustrates this.

Forty five box type solar cookers were distributed to all of the families in Lesobeng, a village in the mountains of central Lesotho. At the end of a year they were given the option to buy them. Only five were purchased. Apparently there is some hope there but many difficulties remain unsolved.

We recommend initiation of a program to develop and introduce stoves and cooking methods of higher efficiency. A proposed model for such a program is presented in Appendix E.

References:

1. T.H. Pierce, "Advisability of adding a forestry component to AID/Praia Watershed project (655-0006)", USAID/Ouagadougou, (1983).

2. "Renewably Energy Project Identification Document (655-0009)", USAID/Praia (1979).

3. G. Yameoga, I. Ouedraogo, and S. Baldwin, "Lab tests of fired-clay stoves, the economics of improved stoves, and steady state heat loss from massive stoves", (1982) and "Lab tests of fired-clay and metal one-pot chimneyless stoves" (1983). CILSS, Ouagadougou and VITA, Washington, DC.

4. Renewable Energy Technology Project, USAID, Maseru, Lesotho (1982).

7. Irrigation with desalinated water:

It has been suggested that desalinated water could be used to irrigate crops. Since the cost of desalinated water would be 150 CVE per cubic meter or higher the crops would have to be of very high value and of very high productivity per unit of land area. More precisely, the value of the crop per unit of water used would have to be high.

Productivities and values of commonly grown crops in Cape Verde are given in Table (VII-7.1) [7.1] . The last column gives the income per hectare paid to the farmer in 1976-77. The highest values per hectare are those for squash and tomatoes, 591,000 and 671,000 CVE/hectare, respectively. If one assumes that each of these crops requires 0.70 meter of irrigation water* the cost of desalinated irrigation water would be 1,050,000 CVE per hectare. Since the irrigation water costs considerably more than the crop is worth it would not be feasible to irrigate with desalinated water under these conditions.

Reports of recent crop yields from Ribeira dos Flamengos [7.2] are listed in Table IV-7.2. The prices are those received by the farmer ("farm gate prices"). Comparing to 1976-77 (Table VII-7.1) one sees that the value/hectare of irrigated crops has not changed appreciably from 1976 and the cost of desalinated water for irrigation would still be equal to or greater than the value of the crop. The potato crop appears to be the most promising since three crops per year can be grown with a water expenditure of perhaps 0.50 meter per crop or an irrigation water cost of 750,000 CVE. This crop is worth slightly more than the cost of the irrigation water.

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* Ref. 7.1 assumes 1.5 meters of irrigation water annually. Squash and tomatoes would use about half of this during a six-month production cycle.

Table VII-7.1. Yields, prices and values, in CVE, of irrigated crops in Cape Verde. Data are for 1976-1977. From Freeman, et al., [7.1].

Crop	Area (ha)	Share (%)	Yield (tonne/ha)	Production (tonne)	Price (tonne)	Value/ha (CVE/ha in 1000's)
Sugar cane	1,065.0	57.5	14.0	14,910.0	-	-
Aguardente	-	-	-	1,704,000.0	5.20	249.5
Bananas	162.0	8.7	42.0	6,804.0	212.49	267.7
Cassava (a)	225.0	12.1	25.0	5,625.0	413.90	310.4
Sweet potato	225.0	-	15.0	3,375.0	357.84	137.0
Potato	132.0	7.1	17.8	2,351.0	474.66	253.6
Carrots	12.3	0.7	13.0	159.3	671.37	260.7
Peppers	4.1	0.2	15.0	61.5	447.47	201.2
Tomato	16.0	0.9	20.0	320.0	984.56	590.8
Cauliflower	3.9	0.2	10.0	39.0	(b) 402.82	120.8
Cabbage	20.5	1.1	10.0 (c)	205.0	402.82	120.9
Leaf cabbage	15.5	0.8	6.0 (c)	93.0	302.11	54.4
Onions	31.5	1.7	12.0	378.0	557.09	193.3
Melons	7.9	0.4	9.0	71.1	-	-
Watermelon	14.0	0.8	40.0	540.0	-	-
Squash	15.5	0.8	50.0	775.0	447.47	671.2
Garlic	21.3	1.2	3.0	63.9	3,524.67	317.2

(a) Cassava and bananas are grown in association

(b) Cauliflower price assumed to be the same as cabbage because of lack of price data on cauliflower

(c) Estimated by team agronomist

(d) Values were given in ref. 7.1 in USD. The conversion back to CVE was made at the approximate exchange rate for 1976-1977 of 30 CVE per USD.

Table VII-7.2. Recent crop yields and farm gate prices in Ribeira dos Flamengos, Santiago (1982-1983). For one crop. From Bedolfe [7.2].

Crop	Yield ($\frac{\text{tonnes}}{\text{hectare}}$)	Price ($\frac{\text{CVE}}{\text{kg}}$)	Sales ($\frac{\text{CVE}}{\text{hectare}}$)
Tomatoes	20	30	600.000
Squash	20	25	750,000
Potatoes	23	40	860,000

What about high value export crops? Could they be economically irrigated with desalinated water? Strawberries from Israel and the U.S. were sold in London for $3.30 to $6.60 USD per kilogram in March, 1983 [7.3]. Other produce prices on the London market ranged from 0.50 to 2.00 USD per kilogram. Air freight costs for produce and fruit are about 0.75 USD per kilogram from Senegal and Mali [7.3] and would probably be similar from Cape Verde.

Let us consider watermelons since they are now imported into London from Senegal and they are also grown in Cape Verde. They sold for 1.33 USD per kg in London in March [7.3]. Productivity on irrigated land in Cape Verde is 40 tonne/hectare. Water costs would be, at 0.60 meters of water per crop, 22.5 CVE/kg or 0.32 USD/kg. After air freight costs of 0.75 USD/kg one would be left with 0.26 USD/kg for other production and sales costs.

With irrigation water of such high cost it would pay to use more efficient irrigation methods such as drip irrigation. This is already practised in Cape Verde (State Farm at Santa Cruz, Santiago, for example). Even covered growing areas (greenhouses) designed to reduce evapotranspiration may be advisable.

With respect to export crops one should keep in mind that growers who service the large central markets in Europe, for example, are in competition with each other. A grower from Senegal who irrigated watermelons with water costing 0.10 USD per tonne would have a decided advantage over one in Cape Verde who irrigated with water costing 2.15 USD per tonne (150 CVE/tonne). The Senegalese grower could sell in London at 0.30 USD per kilogram less than the Cape Verdean grower* Under such a competitive disadvantage it would probably be unwise to invest in an agricultural project using desalinated irrigation water.

To summarize, the use of desalinated water to irrigate does not appear to be cost-effective for either internal or export crops. Exceptions to this may be found for specific crops and special market conditions which have not been identified here. It is important, however, that one does not make the assumption that desalinated water will become inexpensive. We found no evidence earlier that desalinated water can be produced for less than about 150 CVE/tonne in Cape Verde.

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* Using the figures used earlier: 40 tonnes yield per hectare, 150 CVE/tonne water, 0.60 meters of water per crop, exchange rate of 70 CVE = 1 USD.

Note added: The desalinator must be sized to produce the maximum water requirement for a crop. In the southwestern United States, for example, corn and potatoes both require 100 tonnes of water per day per hectare during their maximum period of water requirement [7.4]. Since the water requirement lasts about two months one could irrigate six hectares in rotation of one crop per year for each hectare with a 100 tonne/day desalinator. This would require six hectares each producing one crop per year.

References:

7.1. Freeman, P.H., et al, Cape Verde Assessment of the Agricultural Sector, U.S.A.I.D. Report CR-A-219A, Washington, DC (1978).

7.2. Information communicated by Beto Bedolfe, U.S.A.I.D./Praia.

7.3. Information on London produce prices from the London Financial Times communicated by Frank Dimond, U.S.A.I.D., Praia. Memo to the File, Frank Dimond, Program Officer (April, a983).

7.4. "Consumptive use of water by major crops in the southwestern United States", United States Department of Agriculture, Conservation Research Report number 29, Washington, DC 20250, USA.

VIII. PROJECT RECOMMENDATIONS

By choosing favorable combinations of energy needs, energy resources and energy technologies we have identified some promising areas for development. They are:

- Desalinated water - electrical power production systems powered by combinations of petroleum sources, wind machines and solar ponds,
- More efficient cooking methods and devices,
- Isolated rural electrical power for small water pumping, refrigeration, lighting, communications.

In this section we recommend some development programs based on this selection. They are programs recommended for immediate implementation and long range implementation.

The programs for immediate implementation are:

- Planning for and design of desalination-electricity production system using a combination of petroleum, wind and salt gradient solar ponds. This includes planning for a rejuvenated salt production industry.
- Construction and operation of a solar pond for developing an in-country capability.
- Development and diffusion of more efficient cooking methods and equipment.

The programs for long-range implementation are:

- Establishment of an insolation measurement program,
- Development of a capability in photovoltaic power generation,
- Construction of a solar pond of approximately 65,000 square meters to furnish power to the Sal Island desalination-electricity generation system.

1. Solar pond development:

Solar pond development and employment should proceed in two phases. Phase I would be a development phase in which Cape Verdean personnel would gain experience in solar pond construction and operation. In this phase a 200 square meter pond would be constructed at Praia. Salt from Cape Verdean salt evaporation ponds would be used. The plastic liner, piping, pumps, instrumentation and other necessary tools and equipment would be purchased abroad for the most part.

A measurement program would be carried out to determine the pond behavior under local conditions of temperature, insolation, wind, and atmospheric conditions. This would include measurement of the temperatures and salinity profiles. After reaching operating temperatures, heat would be extracted and efficiency measurements performed. This operation could utilize the heat exchangers of the SOFRETES solar pump at Achada São Filipe.

Experience in generation of mechanical power would be gained by utilizing the SOFRETES motor, heat exchangers, condenser and pump from Achada São Filipe. Cooling water for the condenser would be needed at a rate of 10 to 20 cubic meters per day and water to make up for evaporation would be needed at an average rate of 1 to 2 cubic meters per day so that a location near the ocean (sea water is adequate for both of these requirements) would be advisable.

Phase II would be installation of a larger solar pond of approximately the size (65,000 m^2) analyzed by Burns & Roe (see section VII-2). It would produce electrical power for either an electrical system or a combined electrical-desalination system. The three likely locations are Mindelo, Praia and Palmeira on Sal island.

In Appendix D, a model Phase I project is outlined. It would last three years and require donor funding of 128,000 USD and Cape Verdean funding of 3,300,000 CVE. A 200 square meter pond would be constructed and operated.

The utilization of solar ponds for electricity and desalinated water production (phase II projects) is discussed in Section VII-3.

2. Solar pond and wind supplemented desalination and electricity production:

The discussions of Sections IV, V, VI and VII strongly suggest that work be initiated which will introduce energy from wind machines and solar ponds into electricity and desalinated water production systems. This should start with engineering studies for increasing the capacity of the Sal Island and São Vicente electricity-desalination systems. It should be followed by implementation which has a strong technical and cost performance measurement component.

The Praia and other energy systems will probably expand and incorporate desalination into their systems. As this occurs wind and solar ponds should be utilized to the fullest extent.

The measurement programs on the first systems, as well as the development work carried out by I.N.I.T., will assist the proper introduction of wind and solar pond energy into desalination and electricity production.

A tendency to emphasize wind machines in Cape Verde, because of its almost uniquely strong wind regime for a low-latitude country, appears to work against development of solar electric power sources. This should be avoided. Wind machines can only supply a fraction of the energy needed (usually stated to be 20 % of an electrical system's capacity).* Solar ponds on the other hand can supply 100 % and also develop a sizeable local construction and salt production industry. Although a wind water-pumping industry can be developed in Cape Verde, it is likely that 50-100 kW wind electric machines will continue to be entirely imported.

Therefore, engineering studies aimed at introducing local, renewable energies into the electricity-desalination systems of Cape Verde should include solar ponds and, eventually, photovoltaics.

Since solar ponds will be a major consumer of salt**, planning for a reinvigorated and enlarged salt production industry in Cape Verde should be done concurrently.

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* However, because of the wind speed distribution in Cape Verde it may be higher than 20%. Furthermore, it should be higher for combined desalination-electricity production systems since the desalination can to a large extent fill in the "demand valleys" that are characteristic of city electrical power demand.

** If salt ponds furnished half the power for the São Vicente, Sal, and Praia electricity-desalination systems construction and operation of the ponds over a period of 20 years would consume 2 to 4 million tonnes of salt annually.

3. Improved stoves and cooking methods:

Following the practice of choosing the most promising avenues we shall recommend a program of improvement of conventional cooking techniques. The program would start with a reasonably good survey of cooking technique and quanties and types of fuel consumed in the project area (probably a specific ribeira for the first phase of the project). Then a construction and testing program, located at or near a rural extension center, would commence construction and tests of several types of improved stoves and cooking methods. These could include:

- fired clay stoves
- stoves constructed of stone by Cape Verdean stone construction techniques
- pressure cookers
- insulated boxes
- other

Standard cooking efficiency tests would be made as well as use tests with the cooperation of households and people in the neighborhood. This would include instruction and interchange of ideas on more efficient and fuel conserving procedures as well as use of improved cooking equipment.

As the program progressed effort would be channeled into the more successful developments and techniques.

A model for a project is outlined in Appendix E.

4. Insolation Measurement Program:

Existing measurements of insolation in Cape Verde were reviewed and analyzed in Section III. Most of the measurements were done with a Robtizsh Actinograph of basic accuracy ± 10 %, or worse if not regularly calibrated. A few recent measurements using better instruments showed much lower values of insolation. Therefore, we are still quite uncertain of the true insolation in Cape Verde. Furthermore, only the global (direct plus diffuse) insolation was measured and extensive measurements exist only for Mindelo and Praia. Since design and development of solar energy systems requires good knoledge of insolation a solid program of insolation measurement for Cape Verde is indicated*.

The measurements should be:

a. Measurements of global and diffuse insolation at ten minute, or at most hourly, intervals using accurate pyranometers and electronic readout and recording. Sunshine duration, using the Campbell-Stokes solarimeter, should be carried out simultaneously in order to derive empirical relations between insolation and sunshine duration. Regular calibration and maintenance of the equipment is imperative.

b. These measurements should be done on several islands and in several types of weather zones.

c. A central data reduction and storage facility must be set up to receive, reduce and make available in reports or computer format, the results of the measurements.

d. Analysis of the results in terms of weather parameters should be carried out. Relations between sunshine duration and insolation should be derived for use at locations which have only a Campbell-Stokes solarimeter. Studies of the relation of the diffuse component of insolation to the atmospheric radiation scattering properties (dust or water vapor) should be made.

5. Photovoltaic development:

Photovoltaic systems are already attractive for small remote applications and show promise for larger applications. If predicted priced reductions occur they will become competitive for very large applications. Since this is a good possibility it would seem advisable to develop a photovoltaic capability in the country. This should begin with an emphasis on small remote systems of 25-500 watts peak that provide medical refrigeration, lighting, communications, and in some cases water pumping.

The program would consist of two parts. The first would be purchase of off-the-shelf systems from manufacturers, installing them in rural areas and monitoring their performance. A model of each system might also be tested in the laboratory. The "rural" areas should be reasonably close to Praia so that monitoring of performance could be carried out easily on a regular basis. Off-the-shelf systems that could be bought are (1) photovoltaic refrigerators for medical use which satisfy the specifications of the Center for Disease Control, Atlanta, GA. USA and the World Health Organization, (2) self contained photovoltaic electrical systems with panels, controls, batteries and high efficiency loads (lights, refrigerators, etc.). Some suppliers are ARCO Solar, Solarex, Solar Power and Solavolt.

The second part would attempt to construct systems from components using local materials and skills where possible. Besides the obvious advantage of limiting imports one could possibly reduce the so-called Balance of Systems Costs (BOS Costs) which currently are a more costly part of photovoltaic systems than the photovoltaic panels themselves. For example, panels may cost 10 USD per peak watt but the system may cost 25 USD per peak watt. Local design, materials, and labor could reduce these, the largest part of the cost of the system.

IX. ACRONYMS:

C.D.T.C.	Centro de Documentação Técnica e Científica, Praia
D.G.I.E.	Direcção-Geral de Indústria e Energia, Praia
ELECTRA	Empresa Pública de Electricidade e Água, São Vicente
ENACOL	Empresa Nacional de Combustíveis, São Vicente
U.S.A.I.D.	United States Agency for International Development, Washington DC.
AGRHYMET	AGRicultural-HYdrological-METeorological program for Sahel, Niamey
I.T.D.G.	Intermediate Technology Development Group Ltd., London
I.N.I.T.	Instituto Nacional de Investigação Tecnológica, Praia
D.E.R.	Divisão de Energias Renováveis, Ministério do Desenvolvimento Rural, Praia
CILSS	Commité Interétat pour la Lutte Contre la Secheresse dans le Sahel, Ouagadougou
VITA	Volunteers in Technical Assistance, Washington, DC.
S.W.D.	Steering Committee on Wind-Energy for Developing Countries, Amersfoort, The Netherlands.
O.T.E.C.	Ocean Thermal Energy Conversion.

APPENDIX A.

MEASUREMENTS OF SOLAR RADIATION IN THE REPUBLIC OF CAPE VERDE

C.F. Kooi

Cape Verde Renewable Energy Project (625-0937.03) USAID/Praia

July 29, 1983

The intent of this report is to collect as much data as possible on insolation available in Cape Verde, to present it in a uniform fashion, to indicate the state of knowledge concerning insolation in Cape Verde, and finally to indicate the actions concerning insolation measurements and data collection which are necessary for carrying out solar energy development in Cape Verde.

I. MEASUREMENTS OF SOLAR RADIATION

There are two types of solar radiation measurement commonly done in support of solar energy work. The first is a measurement of "duration" given in hours per unit time interval (hours/day, hours/month, etc.). It is simply the time during which the sun shines strongly enough to burn a hole in a paper placed underneath a glass ball that concentrates the radiation onto the paper. The device is called the "Campbell-Stokes" solarimeter. Since the beginnings and endings of the burnt parts of the paper are not precisely measurable, this is a measurement of low precision. Furthermore, one cannot use "duration" directly in calculating the performance of solar energy systems; assumptions must be made concerning the intensity of radiation while the sun is shining. This will be discussed in Section III.

The second type of measurement determines the amount of radiative energy falling on a certain horizontal area in a certain time interval. This is frequently called "insolation"* and that term will be used here. It is given in units of energy/area time. A wide variety of units are used. We shall use cal/cm2 per unit time interval in this report. The measurement is made with a pyranometer. The two common types in use today employ

(a) thermocouples, one set of junctions being raised by the sun's rays to a higher temperature than the other set thereby producing a voltage

(b) a silicon p-n junction across which the solar radiation produces a voltage by raising electrons from the valence to the conduction band.

The voltage produced by either of these devices is measured and related, by calibration procedures, to the solar radiation power per unit

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* See footnote on page 2.

area falling on the device. The thermocouple type is usually considered to be more accurate because of its broadband spectral response and lower sensitivity to ambient temperature. Instruments of this type have traditionally been the "standard" instruments. However, the silicon cell type appears to be undergoing an improvement process and may soon be as accurate and reliable as the thermocouple type.

A third type was used by the "Serviço Meteorológico Nacional" of Portugal to make insolation measurements at Praia and Mindelo during the years 1955-1973; years for which we have data. It is the Robitzsch actinograph whose sensing element is a blackened bimetallic strip supported at one end and exposed to radiation through a transparent cover. When it absorbs radiation its temperature rises and it bends. The movement of the free end is magnified by mechanical linkages and recorded by an arm and pen onto a rotating drum. It is also known as the Michelson pyranometer. It has the advantage, for remote locations, of being self powered except for the clock mechanism which rotates the registration drum. However, its accuracy is lower than thermocouple types [1,2]; deviations from true value are stated to be 10 % or greater [2], [4].

As sunlight passes through the atmosphere it is not only absorbed but undergoes multiple scattering from dust particles, water droplets, etc. The direct component of insolation is thus reduced and a scattered or "diffuse" component arrives at the measuring instrument along with the reduced direct component. One can measure the direct and diffuse components separately and also the total or "global" insolation which is the sum of the two. In practice, measurement of only two of these three is usually carried out in order to minimize cost and labor. Two identical pyranometers are used, one measures the global insolation, the other mesures the diffuse insolation, the latter being done by simply placing an obstruction (a shadow band) in the direct line to the sun. All insolation measurements giver in this report are "global".

In order to properly design many, if not most, solar energy systems one needs accurate reliable measurements of both diffuse and global insolation on time intervals of approximately ten minutes. This should be done at a number of locations representative mainly of variations in cloudiness.**

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* However, the Anuário Climatológico, referred to later uses "Insolação" to denote "Duration" of sunshine and it uses "Radiação Global" to denote "Insolation". The names "Duration" and "Insolation" as we are using them in this report are more in line with present usage.

** There appear to be large variations in insolation over very short distances on the mountainous islands. This is particularly noticeable, for example, on Santo Antão when crossing from the windward (cloudy) to the lee (sunny) slope between Ribeira Grande and Porto Novo.

II. DATA

The Anuário Climatológico de Portugal [3] contains measurements of global insolation and sunshine duration for a number of years. The insolation measurements were taken with the Robitzsch bimetallic actinograph and the sunshine duration measurements with a "heliograph", presumably of the Campbell Stokes type. Insolation data in calories per square centimeter per month for the years 1955, 1956, 1957 and 1960 through 1973 were obtained and are presented in Table I for Praia and Table II for Mindelo. These tables contain the maximum daily insolation for each month.

Insolation data for 12 to 16 years* was averaged and are presented in Tables III and IV. In addition to the mean the minimum and maximum (and the years in which they occured) and the standard deviation are presented. The mean of the monthly total is divided by the number of days in the month and this daily mean is presented in the seventh column. The daily means from the report of Løf, Duffie, and Smith [2] are presented in the eighth column. Løf, et al., obtained these data from the Boletim Actinométrico de Portugal, Ano I-V, Lisboa. They are averages for 4-5 years. The years are not specified but they are prior to 1966, the data of their report. The agreement between those two sets of data, columns 7 and 8, is quite good. This is not surprising since it was probably obtained from the same measurement program; only the years in the data sets would differ.

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* Years for which we had complete data for <u>both</u> Praia and Mindelo.

TABLE I. GLOBAL INSOLATION (cal/cm2): PRAIA

Month	1955*		1956*		1957*		1960*		1961*		1962*	
	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day
JAN	-	-	16 142	676	13 370	636	13 767	535	11 884	500	10 592	440
FEB	15 053	644	14 718	704	16 091	636	14 914	602	12 188	528	12 176	630
MAR	17 062	680	21 394	792	21 109	777	19 613	668	14 553	594	18 967	698
APR	19 337	701	21 595	784	21 892	790	18 783	687	16 062	582	18 337	690
MAY	19 946	756	21 413	766	22 560	821	19 640	537	15 037	525	23 679	751
JUN	18 441	729	19 553	780	21 334	823	17 845	669	14 750	559	18 050	737
JUL	16 644	733	18 643	868	17 502	724	16 155	663	13 712	566	15 634	636
AUG	16 993	732	17 892	792	-	-	14 577	617	13 601	591	12 255	624
SEP	14 571	665	16 883	725	-	-	14 428	618	-	-	14 801	603
OCT	15 559	614	18 186	697	-	-	14 914	618	-	-	14 827	596
NOV	16 377	641	14 316	617	13 270	534	12 530	501	12 526	510	12 287	556
DEC	14 740	572	11 203	622	11 026	585	10 223	458	12 172	459	11 314	529
Total	-	-	212 068	800	-	-	187 389	687	-	-	179 919	751

Month	1963*		1964*		1965*		1966*		1967*		1968*	
JAN	12 941	553	12 959	680	9 234	355	12 612	470	12 874	523	12 963	533
FEB	13 575	652	11 364	489	10 819	435	12 488	526	13 155	602	14 805	626
MAR	18 321	725	14 087	505	17 879	655	15 581	594	16 354	623	19 172	687
APR	18 973	709	13 296	535	19 332	694	14 146	625	19 620	722	20 711	765
MAY	15 722	559	14 997	532	20 385	693	19 379	687	18 628	668	22 917	813
JUN	19 032	744	13 892	519	21 850	883	17 290	684	-	-	21 331	850
JUL	15 831	612	11 915	489	18 740	809	17 036	609	17 354	669	18 226	762
AUG	15 884	592	11 612	480	17 849	762	15 132	660	16 091	713	18 877	742
SEP	15 358	608	11 040	452	13 234	609	13 117	572	12 953	605	15 378	607
OCT	14 238	659	10 835	439	11 459	504	13 724	645	12 406	534	15 593	634
NOV	15 427	636	9 934	396	10 999	447	12 224	505	11 879	494	12 550	492
DEC	11 620	574	8 566	349	10 756	410	11 748	467	12 529	474	11 237	471
Total	186 369	744	145 497	680	182 546	883	177 477	687	-	722	203 740	830

* Measurements from Anuário Climatológico de Portugal [3].

TABLE I. (continued)

Month	1969*		1970*		1971*		1972*		1973*	
	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day
JAN	12 478	512	12 537	482	13 399	503	11 582	526	12 490	474
FEB	13 720	553	10 875	493	13 857	599	13 433	545	11 760	560
MAR	17 960	616	15 994	571	-	-	16 377	686	15 795	596
APR	17 563	683	17 500	635	18 543	686	20 181	741	16 781	629
MAY	19 884	694	18 130	649	19 521	670	20 280	736	19 525	673
JUN	-	-	18 879	645	19 698	726	18 365	747	17 302	684
JUL	16 883	653	15 534	627	17 385	697	18 838	717	15 867	633
AUG	15 229	626	14 184	615	14 049	639	17 271	652	14 556	614
SEP	13 821	567	13 563	539	15 222	594	15 587	613	15 406	603
OCT	13 550	527	14 179	544	14 652	545	14 852	552	14 284	550
NOV	12 443	472	12 579	483	11 135	456	12 163	496	12 140	483
DEC	10 934	415	10 248	404	11 138	443	11 682	465	11 163	408
Total	-	694	172 815	649	-	726	191 151	747	177 069	684

TABLE II. GLOBAL INSOLATION (cal/cm2): MINDELO

Month	1955*		1956*		1957*		1960*		1961*		1962*	
	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day
JAN	12 526	553	15 213	612	11 068	543	13 466	551	12 916	544	12 666	510
FEB	13 654	595	15 989	711	14 814	612	15 379	681	14 940	633	12 928	577
MAR	17 124	690	20 504	826	20 104	711	21 113	499	19 424	723	18 859	719
APR	19 502	718	21 483	816	21 702	783	20 639	775	21 507	818	19 777	719
MAY	20 167	736	21 945	786	22 987	765	21 116	775	22 548	799	21 331	747
JUN	19 115	780	18 383	781	20 318	767	20 718	844	19 461	747	18 336	731
JUL	17 128	751	19 410	766	18 112	707	18 112	741	16 764	728	17 856	688
AUG	16 171	745	18 825	763	16 224	703	18 293	754	17 546	681	16 361	663
SEP	16 194	737	16 713	715	15 893	602	14 375	683	15 686	637	15 874	638
OCT	15 639	725	16 975	696	15 362	600	15 544	652	15 808	599	13 660	589
NOV	16 036	622	12 354	676	13 443	600	13 180	583	13 104	505	11 412	523
DEC	13 457	592	11 397	532	12 104	610	10 041	500	12 788	480	10 739	412
Total	197 014	786	209 185	820	199 851	785	202 476	844	202 492	818	189 799	747

Month	1963*		1964*		1965*		1966*		1967*		1968*	
JAN	14 987	666	12 652	551	11 200	499	12 280	514	12 504	529	12 992	317
FEB	17 287	764	14 257	607	14 157	602	13 427	590	13 427	590	14 702	631
MAR	20 120	–	16 134	606	18 551	696	12 950	680	17 518	701	19 553	680
APR	19 993	762	19 862	742	20 407	757	19 749	713	20 580	729	20 055	736
MAY	19 079	742	19 797	722	21 319	314	20 488	716	20 765	777	21 548	750
JUN	19 700	–	19 188	766	18 913	716	17 893	718	18 009	720	20 077	745
JUL	18 175	725	16 663	709	17 006	677	18 645	734	18 081	696	18 389	755
AUG	16 304	687	15 892	662	16 220	657	16 730	698	16 215	664	16 764	698
SEP	15 851	724	15 563	679	14 823	654	14 595	635	14 425	677	–	–
OCT	14 876	584	13 889	578	13 916	605	14 111	593	13 155	573	–	–
NOV	14 919	559	12 568	516	12 977	531	11 984	495	12 242	512	–	–
DEC	11 351	486	11 507	460	10 669	474	11 406	479	11 724	480	–	–
Total	202 649	776	189 977	766	189 912	314	189 964	774	188 645	777	–	755

* Measurements from Anuário Climatológico de Portugal [3].

TABLE II. (continued)

Month	1969*		1970*		1971*		1972*		1973*	
	Total	Max day	Total	Max day	Total	Max day	Total	Max day	Total	Max day
JAN	12 310	505	13 506	545	-	-	12 152	541	12 706	552
FEB	13 472	536	12 493	567	-	-	12 746	617	11 643	573
MAR	16 609	59[illegible]	17 568	670	-	-	17 596	756	16 987	662
APR	17 051	642	18 824	687	-	-	22 772	829	17 483	645
MAY	18 231	631	18 699	710	-	-	23 753	868	17 038	612
JUN	16 272	614	18 435	714	-	-	19 559	818	15 756	644
JUL	16 299	606	18 204	684	-	-	17 889	746	15 446	601
AUG	15 025	604	16 612	686	-	-	16 208	676	12 913	585
SEP	13 694	575	16 027	663	-	-	17 802	691	13 738	549
OCT	12 721	511	16 119	615	-	-	15 175	580	13 585	528
NOV	11 105	434	13 399	528	-	-	12 844	566	11 272	455
DEC	9 993	380	13 554	536	-	-	12 725	575	9 934	394
Total	172 782	642	193 440	714	-	-	201 221	868	168 501	662

TABLE III. INSOLATION IN CAL/CM^2 FOR PRAIA

Month	N (nº of years in the data set)	MIN. of monthly total	MAX. of monthly total	MEAN of monthly total	STD.DEV. of monthly total	MEAN of daily total	LOF DUFFIE SMITH
J	15	9,234 (1965)	16,142 (1956)	12,546	1,508 (12.0%)	405	466
F	16	10,819 (1965)	16,091 (1957)	13,338	1,573 (11.9%)	468*	531
M	16	14,078 (1964)	21,394 (1956)	17,545	2,155 (12.3%)	566	630
A	16	13,781 (1973)	21,992 (1957)	18,026	2,630 (14.6%)	601	672
M	16	14,997 (1964)	23,679 (1962)	19,547	2,610 (13.4%)	631	642
J	14	13,892 (1964)	21.850 (1965)	18,380	2,276 (12.4%)	613	621
J	16	11.915 (1964)	18,838 (1972)	16,552	1,869 (11.3%)	534	535
A	15	11,612 (1964)	18,877 (1968)	15,466	2,095 (13.5%)	499	494
S	13	11,040 (1964)	16,886 (1956)	14,132	1,541 (10.9%)	471	514
O	13	10,835 (1964)	18.186 (1956)	14,078	1,861 (13.2%)	454	512
N	15	9,934 (1964)	16,377 (1953)	12,730	1,610 (12.6%)	424	446
D	13	8,566 (1964)	14,740 (1955)	11,335	1,331	366	389

---

* allows for leap years in the data set

The spread of data for Praia is 50 % to 100 % greater than that for Mindelo. This is exhibited by the percentages below each value of standard deviation (columns six) which are the ratios of standard deviation to mean.

The Instituto Nacional de Investigação Tecnológica (I.N.I.T.) in cooperation with the Italian cooperation program measured global insolation at Porto Mosquito on the southwest coast of Santiago Island (a location near sea level) for one year. The data are presented in Table V. for monthly totals. and Table VI for hourly totals for three clear days [4]. These measurements were made with a silicon solar cell pyranometer and an electronic counter-integrator.

Global insolation measurements have begun at São Jorge, Santiago Island, at an elevation of 320 meters under the program of AGRHYMET*. Initial results of this measurement program are presented in Table VII (monthly totals of global insolation) and Table VIII (daily totals) [5]. These measurements were made with a thermocouple type pyranometer read by an electronic counter-integrator.

The latitudes, longitudes and elevations of these four stations are given below:

Mindelo. S. Vicente	16° 52' N	25° 00' N	sea level
Praia. Santiago	14° 54' N	23° 31' W	sea level
Porto Mosquito, Santiago	14° 56' N	23° 41' W	sea level
São Jorge, Santiago	15° 03' N	23° 37' W	320 meters

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* AGRicultural HYdrometry and METeorology measurement program for the Sahel with headquarters in Niamey.

TABLE V. GLOBAL INSOLATION (cal/cm2-month) · PORTO MOSQUITO*

Month	1981	1982
January	-	12 157
February	-	12 223
March	-	13 330
April	-	13 932
May	-	14 930
June	-	13 545
July	-	13 357
August	-	12 797
September	-	12 642
October	-	12 570
November	12 578	-
December	10 984	-

* Measurements by I.N.I.T. (G. Colasante).

TABLE VI. HOURLY INSOLATION ON CLEAR DAYS (cal/cm2-hr): PORTO MOSQUITO*

Time	December 7, 1981	August 30, 1982	March 3, 1982
06 00	0	0.77	0.00
07 00	0.95	3.53	0.60
08 00	11.27	25.80	8.43
09 00	44.20	44.72	28.64
10 00	58.48	60.46	46.44
11 00	67.42	69.49	62.61
12 00	73.87	79.46	68.54
13 00	69.66	72.24	63.90
14 00	61.75	63.04	59.17
15 00	48.16	57.96	43.00
16 00	34.31	38.18	28.81
17 00	20.64	24.51	15.91
18 00	8.08	9.12	5.68
19 00	0	0.00	0.00
Total (Cal/cm2-day)	498.80	548.68	431.72

* Measurements of I.N.I.T. (G. Colasante).

TABLE VII. GLOBAL INSOLATION (cal/cm2-month): SÃO JORGE *

Month	1982	1983
January	-	10 202
February	-	-
March	-	-
April	-	-
May	-	-
June	-	-
July	-	-
August	8 699**	-
September	10 377	-
October	11 561	-
November	10 790	-
December	8 516	-

* Data from AGRHYMET station at São Jorge (Rui Silva).

* 6 days of data missing. Average assumed for these 6 days.

TABLE VIII. GLOBAL INSOLATION (cal/cm2-day): SÃO JORGE

Day of month	1982 August	September	October	November	December	1983 January
1	-	141.	478.	387.	303.	295.
2	-	238.	457.	477.	203.	51.
3	-	471.	368.	402.	369.	178.
4	-	287.	469.	458.	393.	62.
5	-	226.	442.	431.	417.	277.
6	-	386.	320.	470.	168.	248.
7	-	504.	430.	491.	210.	255.
8	-	488.	410.	306.	179.	311.
9	-	265.	479.	424.	267.	361.
10	-	495.	442.	403.	341.	362.
11	377.	327.	442.	385.	294.	240.
12	186.	352.	336.	360.	235.	367.
13	222.	323.	450.	324.	219.	339.
14	374.	316.	164.	371.	209.	330.
15	360.	217.	225.	201.	183.	316.
16	214.	241.	257.	190.	176.	265.
17	190.	464.	283.	315.	276.	339.
18	220.	247.	373.	413.	310.	396.
19	514.	249.	394.	413.	279.	425.
20	340.	376.	148.	379.	164.	441.
21	192.	366.	354.	372.	224.	442.
22	283.	348.	269.	443.	367.	448.
23	204.	362.	405.	363.	229.	[illegible]
24	230.	432.	225.	378.	202.	457.
25	263.	474.	454.	226.	387.	457.
26	252.	428.	480.	362.	329.	345.
27	398.	205.	497.	97.	309.	385.
28	69.	215.	430.	169.	360.	286.
29	290.	457.	346.	359.	333.	283.
30	486.	472.	362.	419.	311.	366.
31	269.		370.		271.	420.

Measurements of AGRHYMET station at São Jorge (Rui Silva).

III. DISCUSSION OF INSOLATION DATA

The average daily insolation for Praia and Mindelo, from columns seven of Tables III and IV, is shown in Figure 1. The less extensive measurements from Porto Mosquito and São Jorge, as derived from Tables V and VII, are also shown. The annual variations are obviously caused by (a) the seasonal variations of the declination of the sun, (b) the rainy season in the late summer and fall and (c) the dusty season in the winter.

The differences between the measured insolation for Mindelo and Praia must be due to different atmospheric conditions or to systematic instrument error. It is too large to be attributable to the latitude difference of only 2 degrees.

The differences between the measured insolation for Mindelo - Praia and Porto Mosquito are almost certainly measurement inaccuracies since these are all coastal, low elevation locations. The lower values for São Jorge, however, may be due to its elevation, 320 meters, and the consequent increased cloudiness and rainfall; but instrument inaccuracy may also be present.

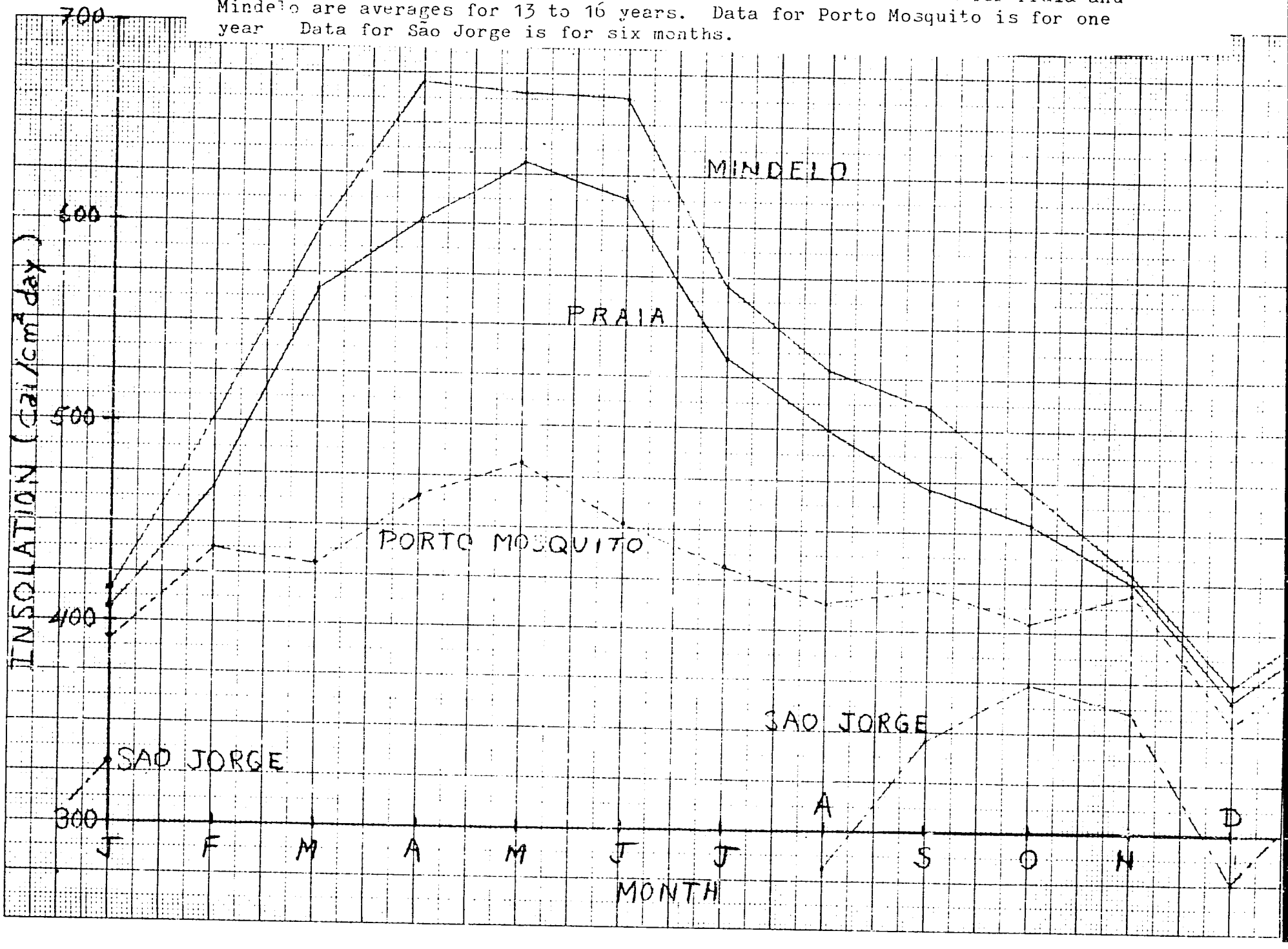
We may make an additional estimate of the reliability of the Cape Verdean measurements by comparing them to the measurements and derived data for the continent. Data for sites at similar latitudes in Senegal and Mauritania are shown in Figure 2 (Henri Masson [6]). By comparing these data (i.e., Figs. 1 and 2) one is led to suspect that the summer and fall data for Mindelo and Praia are too high while those of Porto Mosquito may be somewhat low. The data from São Jorge is still too sparse (only five months yet available) to draw any conclusions.

The continental climate, of course, is not exactly the same as the Cape Verdean climate, but its latitude, rainy season and the dusty season are similar. Furthermore, the accuracy and reliability of the Dakar measurements are quite good because of the better instrumentation, calibration program, and professional attention that this measurement program received [6].

Reference to columns six of Tables III and IV reveals that the dispersion of measurements about the mean is much larger for Praia than for Mindelo. This would appear to be an artifact of the measurements in Praia and Mindelo since the meteorological situation is not much different one from the other. Adding this apparent measurement inaccuracy to the known low accuracy of the bimetallic type of instrument which was used, and in light of the previous discussion, we must conclude that existing measurements of insolation in Cape Verde are not of good accuracy and more accurate measurements are needed.

In order to design and calculate the performance of most solar energy devices the engineer needs insolation data on an hourly basis although

Fig. 1. Average daily insolation as a function of month. Data for Praia and Mindelo are averages for 13 to 16 years. Data for Porto Mosquito is for one year Data for São Jorge is for six months.



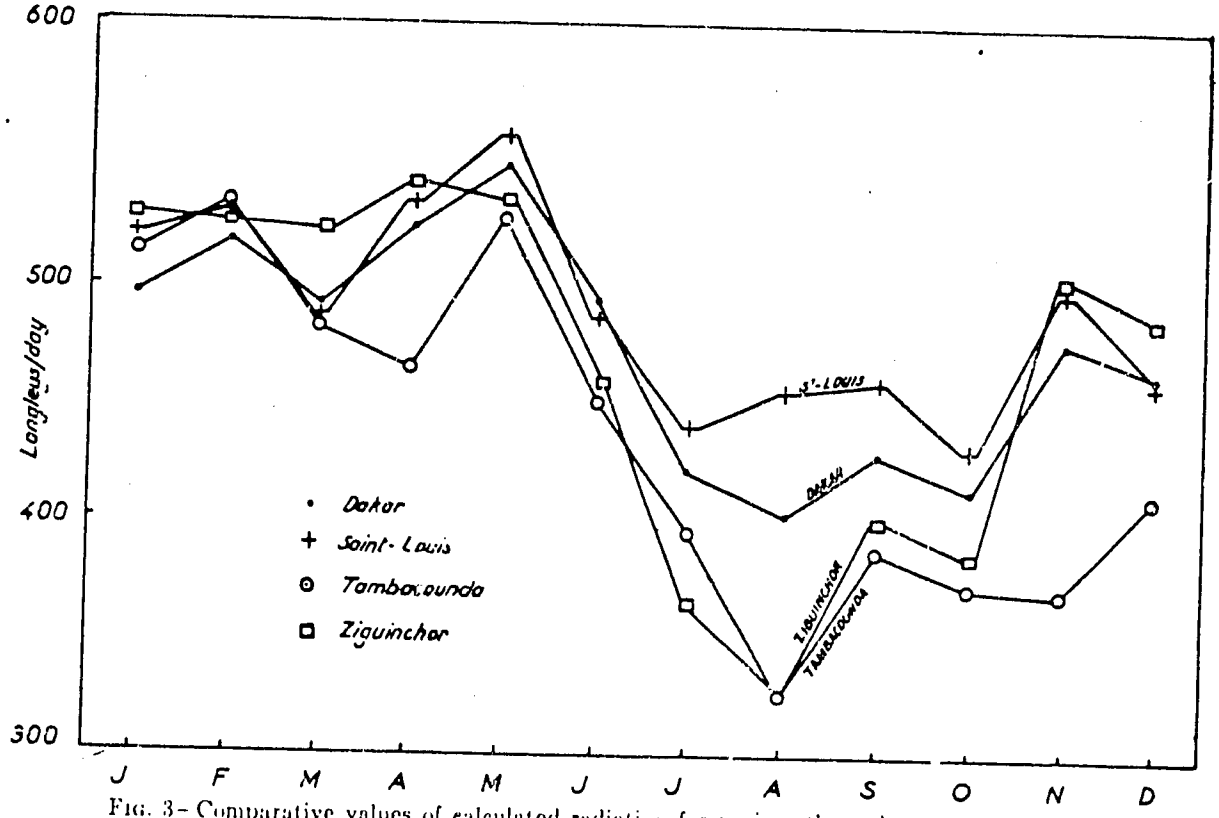


FIG. 3 – Comparative values of calculated radiation for various Senegalese towns. (1963)

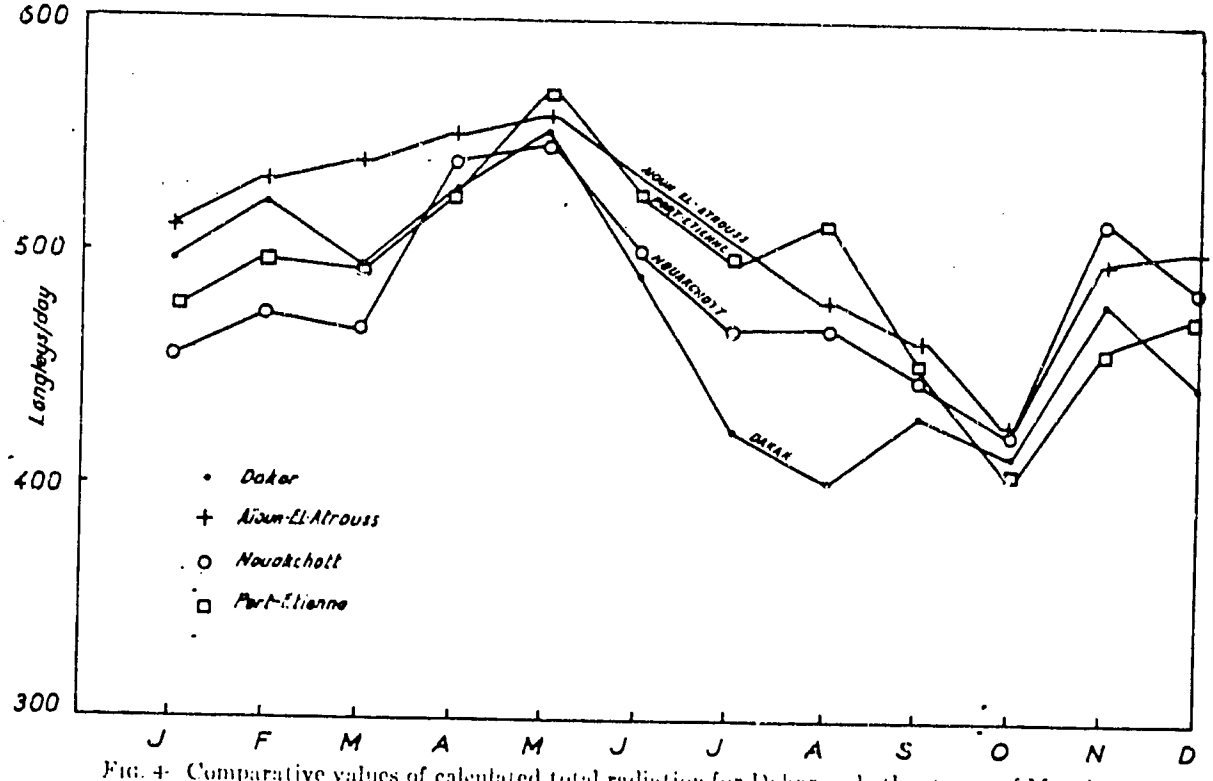


FIG. 4 – Comparative values of calculated total radiation for Dakar and other towns of Mauritania. (1963)

Fig. 2. Average daily insolation for locations in Senegal and Mauritania (From Masson [6]). The data for Dakar are measured; for the other cities they are derived from sunshine duration data.

occasionally data on a daily or monthly basis is sufficient. Very little hourly or daily data is available in Praia. The little we have is shown in Tables VI and VIII. All of the data from the Anuário Climatológico was taken on a continuous basis as recorded on the rotating drum of the Robitzch actinograph. Therefore, a vast amount of hourly data was in existence at one time. However, we do not know whether these continuous records still exist.

In order to design and calculate the performance of some solar energy devices, particularly concentrators, the engineer must know the portion of insolation which is direct. We do not know of any measurements of direct and diffuse insolation for Cape Verde.

Preliminary indications from the insolation measurements at São Jorge and deduction from cloudiness and rainfall information indicate that there are large variations in insolation in the Cape Verde Islands. These variations would be expected to depend on altitude and, perhaps on the location with respect to windward or leeward sides of mountainous regions. Except for the very preliminary results from São Jorge we have no measurements of these variations.

Measurements of sunshine duration have been made at a number of stations in Cape Verde for many years (see Anuário Climatológico, [3]). These include Mindelo, Praia, Sal, and Água das Caldeiras (Santo Antão). Because this is a cheaper and easier measurement to make it is more widespread. Therefore, it is common practice to attempt to derive insolation data from sunshine duration data.

This is usually done by graphing insolation, I, versus hours, S, and fitting an analytic expression to the data by a least squares or regression, process. We have constructed such graphs for the monthly totals for Mindelo (Figure 3) and Praia (Figure 4) using the insolation data in Tables I and II and the sunshine duration data (called "insolação") from the Anuário Climatológico [3]. Some years for which complete data on both insolation and duration for both Praia and Mindelo were selected from the Anuários at our disposal.*

It is immediately obvious from these graphs that the relation between insolation (I) and hours of sunshine (S) is different for the "dusty" winter months (November, December, January, February) and the "cloudy" summer and fall months (July, August, September, October). The former group lies lower on the graphs than the latter. This may be due to the different light scattering and attenuation properties of dust and water, as well as to the greater atmospheric path length and lower average angular altitude of the sun during the winter.

We first use the simplest possible equation to relate I to S. It is

$$I = a + bS \qquad (1)$$

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* Presumably other volumes exist which have suitable data.

Fig. 3. Total monthly insolation as a function of total monthly sunshine duration for six years at Mindelo. The lines are regression fits to the data as described in the text and Appendix A.

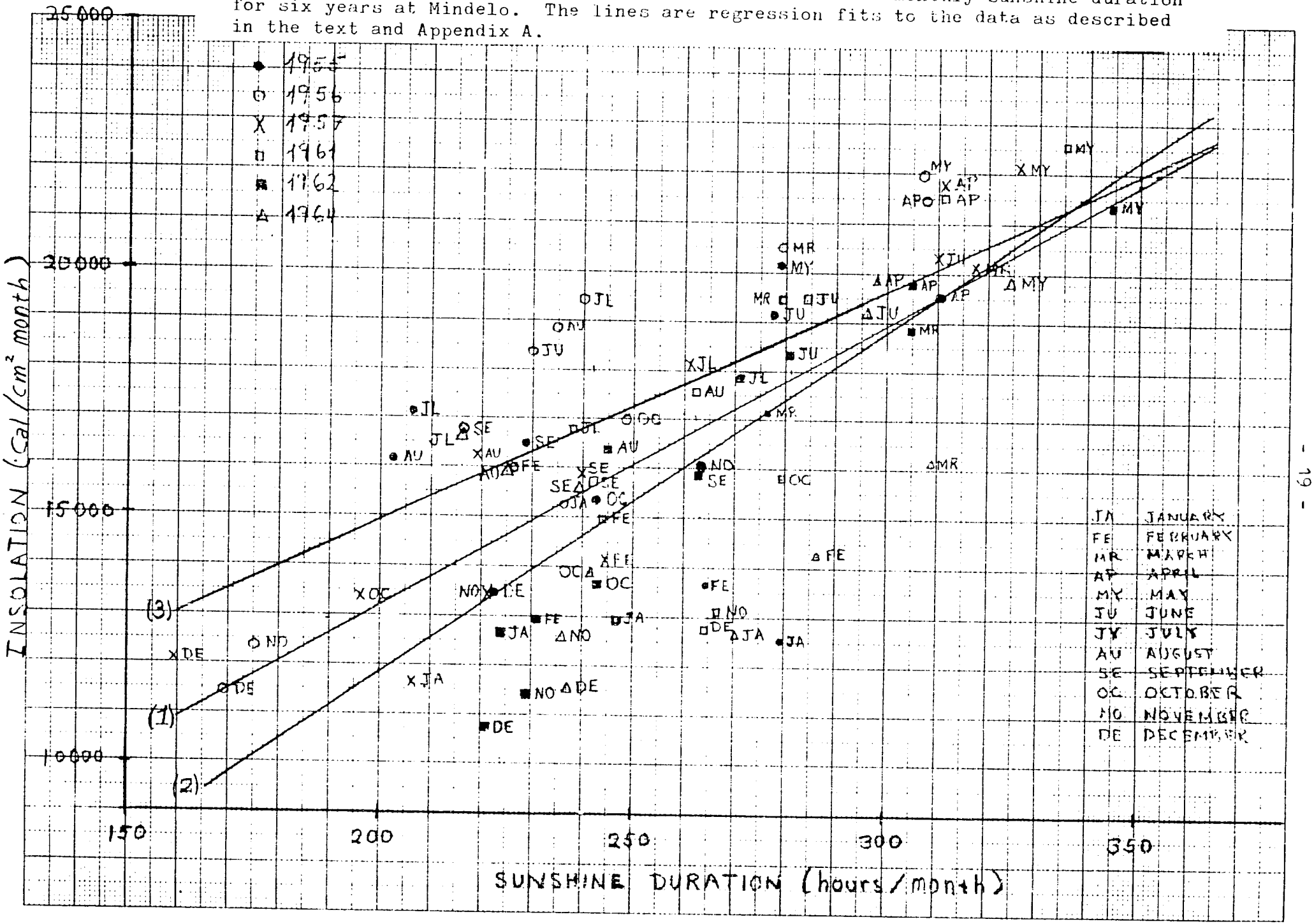
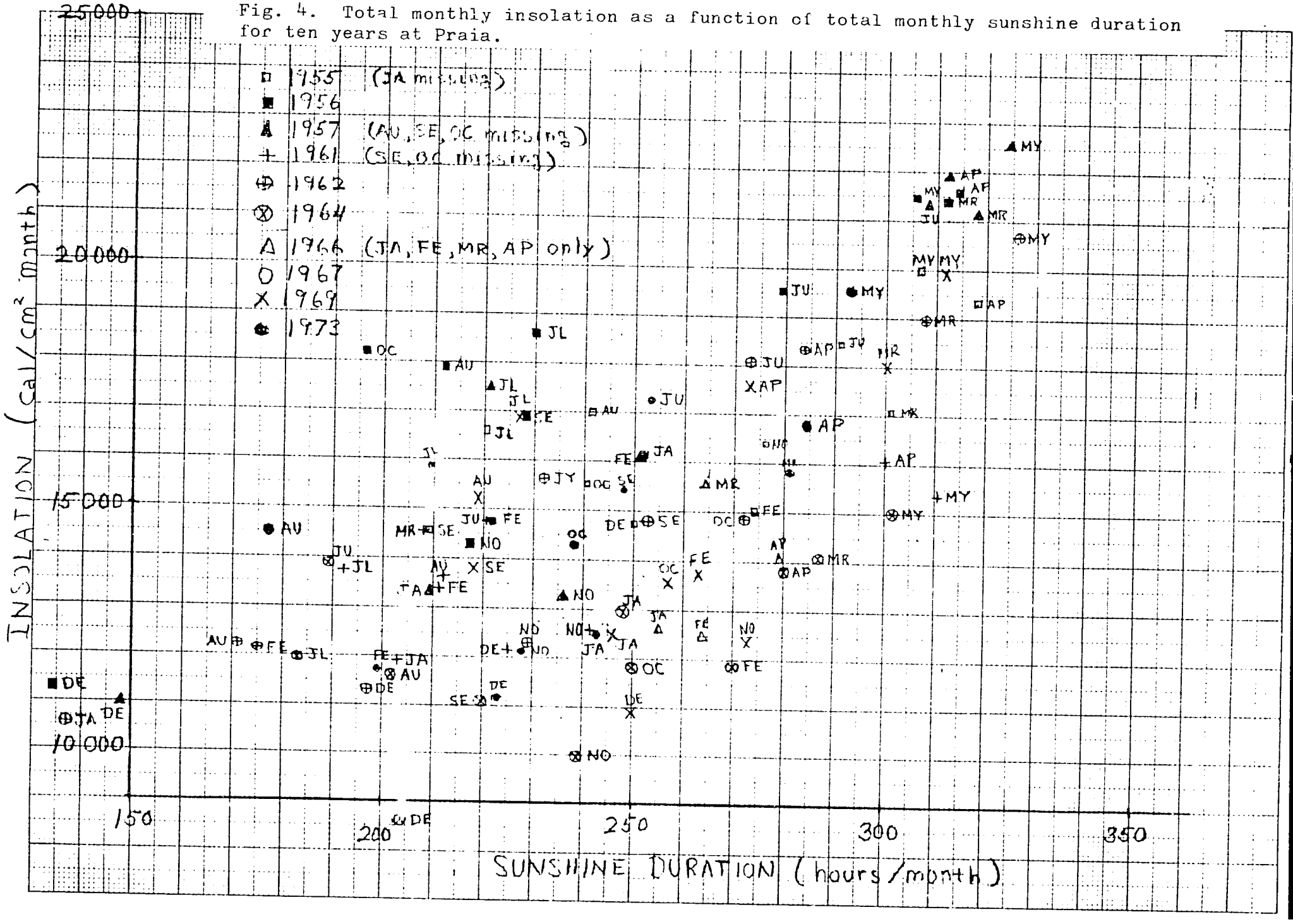


Fig. 4. Total monthly insolation as a function of total monthly sunshine duration for ten years at Praia.



where: I is the insolation in cal/cm2 month
a, b are constants
S is the sunshine duration in hours/month.

We made a least squares (regression) fit of this equation to the Mindelo data for 1955, 1956, 1957, 1961, 1962, 1964 in three ways: (1) using all data, (2) eliminating the data for the "cloudy" months, and (3) eliminating the data for the "dusty" months. The results are:

	a	b	r^2
(1) No months excluded	1843	56.97	0.57
(2) "Cloudy" months excluded	-1998	69.36	0.66
(3) "Dusty" months excluded	5574	46.85	0.58

The "coefficient of determination", r^2, is also listed. It indicates a good fit for values close to 1 and a poor fit for values close to 0. Evidently, splitting the data into the latter two groups gives a better fit than fitting the data from all the months to a single curve as for case (1). These regression lines are shown on Figure 3 and labelled (1), (2) and (3) in accordance with the scheme above.

A somewhat better way of fitting an analytic expression to the data is based on work of Ångström [7]. The monthly sums of radiation, I, are divided by the amount of radiation available at the location outside the atmosphere, I_o, and the numbers of sunshine hours per month, S, are divided by the maximum number of sunshine hours at the location outside the atmosphere, S_o. These ratios are assumed to be related by

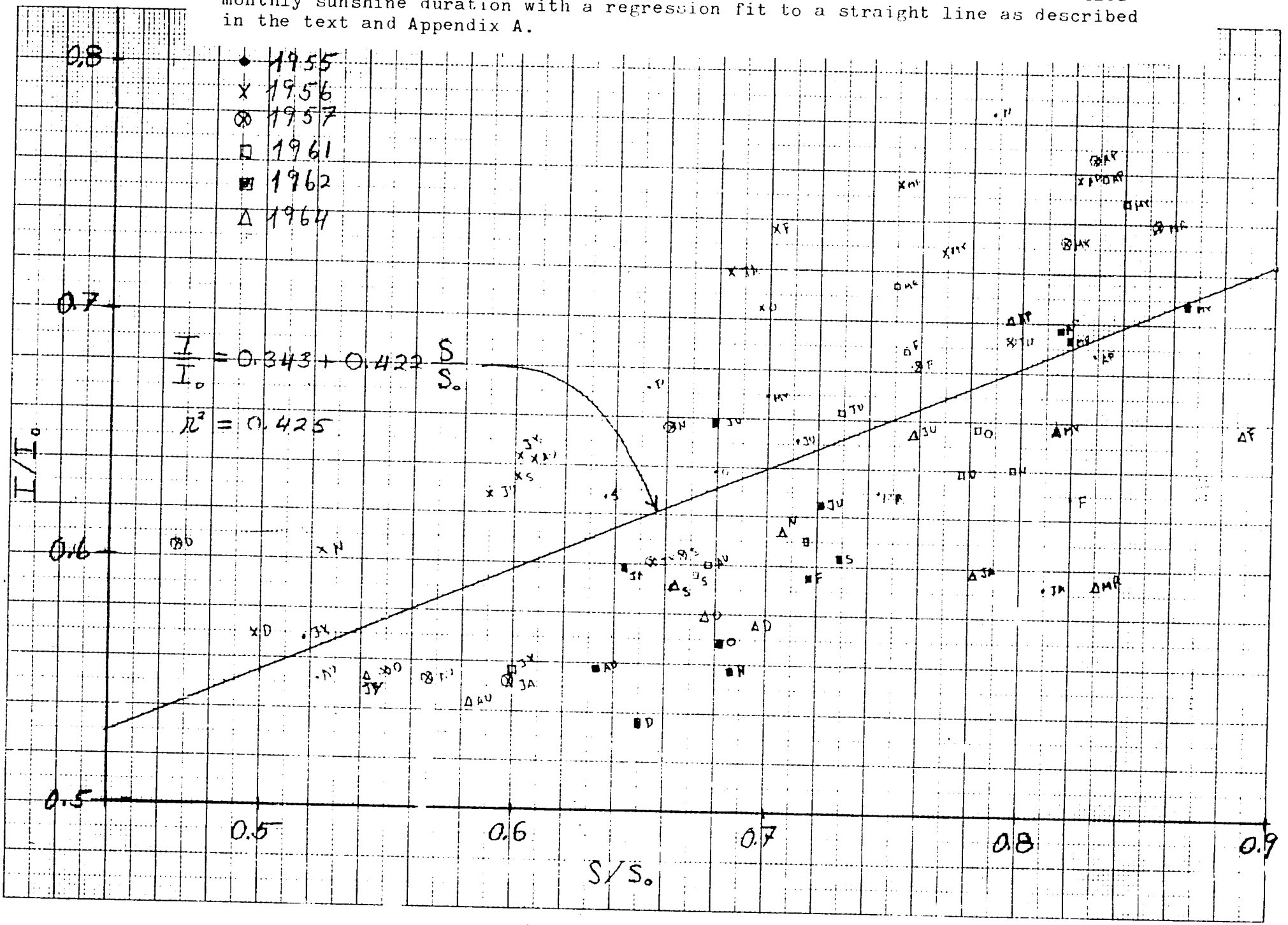
$$\frac{I}{I_o} = a + b\frac{S}{S_o} \qquad (2)$$

where a and b are constants.

We have calculated I/I_o for each month for the years 1955, 1956, 1957, 1961, 1962, and 1964 for Mindelo and presented the results in Figure 5. A regression fit to Eq. 2 is also shown on this Figure. The constants are a = 0.343 and b = 0.422. The coefficient of determination r^2 = = 0.425. This value of r^2 is lower than those obtained for Eq. (1) and one would conclude that one could do better by using Eq. 1 to calculate insolation from sunshine hours data at low altitude sites in Cape Verde. Eq. 1 would be even more valid if one used the equations for "cloudy" and "dusty" months separately (cases (2) and (3) above).

It should be noticed, however, that the "cloudy" and "dusty" months do not lie in distinct regions on the I/I_o versus S/S_o plot (Fig. 5) as they do on the I versus S plot (Fig. 4). This may indicate that the grouping observed in Fig. 4 may be due to the relation path length through the atmosphere rather than to the different radiation scatter-

Fig. 5. Normalized monthly insolation for Mindelo as a function of normalized monthly sunshine duration with a regression fit to a straight line as described in the text and Appendix A.



ing and absortion properties of water and dust in the atmosphere. However, it could be useful to determine the different scattering and absortion properties of water and dust since there are distinct "cloudy" and "dusty" seasons in Cape Verde and, indeed, in large parts of West Africa (see Appendix B).

V. CONCLUSIONS

Sufficient information exists to allow one to design solar devices and systems at locations in Cape Verde that are at low elevations. However, the largest body of data, that for Mindelo and Praia from 1955 to 1973, does not appear to be accurate. Other data is still too sparse to significantly remedy this state of affairs. Therefore, calculations of the performance of solar systems can presently be done only to low accuracy with perhaps 10 to 20 % errors just due to the uncertainty of the insolation data. Furthermore, there is almost no information on insolation at higher elevations and none at all on the diffuse component of insolation.

A strong insolation measurement program is needed in order to provide the basis for utilization of solar energy in Cape Verde. Measurements of diffuse and total insolation should be made at a variety of locations and these should be carried out for at least a decade. In addition measurements of sunshine duration, a cheaper and easier measurements, should be made at many more locations and used to calculate insolation by methods such as those of the previous section.

VI. ACKNOWLEDGEMENTS

I wish to thank Giovanni Colasante, of I.N.I.T. for useful discussions, for providing the insolation data of Porto Mosquito and for collecting and transmitting insolation data from Lisbon, Daniel Pires of the Centro de Documentação Técnica e Científica, Praia, for obtaining copies of the Anuário Climatológico from Ilha do Sal, and Antonino Nunes for typing the manuscript.

FIGURE CAPTIONS

1. Average daily insolation as a function of month. Data for Praia and Mindelo are averages for 13 to 16 years. Data for Porto Mosquito is for one year. Data for São Jorge is for six months.

2. Average daily insolation for locations in Senegal and Mauritania (From Masson [6]). The data for Dakar are measured; for the other cities they are derived from sunshine duration data.

3. Total monthly insolation as a function of total monthly sunshine duration for six years at Mindelo. The lines are regression fits of Eq. (1) to the data as described in the text and Appendix A.

4. Total monthly insolation as a function of total monthly sunshine duration for ten years at Praia.

5. Normalized monthly insolation at Mindelo as a function of normalized monthly sunshine duration with a regression fit to Eq. (2) as described in the text and Appendix A.

VII. REFERENCES

1. Perrin de Brichambaut, C. and Lamboley, G., Le Rayonnement Solaire au Sol et Ses Mesures, Cahiers A.F.E.D.E.S. No. 1. janvier 1968. Association Française pour l'Etude et le Développement des Applications de l'Energie Solaire, 28, rue de la Source, 75016 PARIS. p. 49.

2. Déf. G.O.G., Duffie, J.A., and Smith, C.O., World Distribution of Solar Radiation. Report No. 21. Solar Energy Laboratory. The University of Wisconsin, Madison, Wisconsin. (1966).

3. Anuário Climatológico de Portugal. Serviço Meteorológico Nacional, Lisboa.
(a) for 1960 - 1973. II Parte, Territórios Ultramarinos
(b) for 1955 - 1957, I Parte, Ilhas do Atlântico - Norte

4. Giovanni Colasante (I.N.I.T., Praia) private communication.

5. Data made available by Rui da Silva of AGRHYMET, São Jorge dos Órgãos, Santiago.

6. Masson, H., Quantitative Estimation of Solar Radiation. Solar Energy, vol. 10, No. 3, p. 119 (1966).

7. Angström, A., Solar and Terrestrial Radiation, Quarterly J. Royal Meteorological Society, vol. 50, p. 121 (1924).

8. Onyango, F.N., On the Estimation of Global Solar Insolation, Solar Energy, vol. 31, nº 1, pp. 69-71 (1983).

Appendix AA. CURVE FITTING AND CALCULATION OF I_o AND S_o (EXTRA-ATMOSPHERIC INSOLATION AND SUNSHINE DURATION)

The equations

$$I = a + bS \tag{1}$$

or

$$I/I_o = a + bS/S_o \tag{2}$$

were fit to the data using a standard regression program for the HP 97 desk calculator. No standard program for calculation of I_o and S_o is available. These quantities were calculated as follows.

The angle from vertical, V, of a line from the sun to a point on the earth's surface at latitude, L, is given by

$$\cos V = \cos H \cos D \cos L + \sin D \sin L \tag{3}$$

where H is the hour angle which is zero at local noon and measured positively in afternoon, i.e., 15° = 1300 hours, 30° = 1400 hours, etc. D is the solar declination angle which, to acceptable precision, is given by

$$D = 23.45 \sin (2\pi n/365) \qquad \text{in degrees} \tag{4}$$

where n is the number of days after the spring equinox. The sunset and sunrise hour angle is found by setting $V = 90^o$ in Eq. 3.

$$H_s = - \tan L \tan D \qquad \text{in degrees} \tag{5}$$

The number of hours in the day is

$$S_o^{\,d} = \frac{1}{15} \int_{-H_s}^{+H_s} dH = \frac{2H_s}{15} \tag{6}$$

and the insolation per day outside the atmosphere is

$$I_o^d = K \int_{-S_o/2}^{+S_o/2} \cos V \; dt \tag{7}$$

where K is the "solar constant" taken to be equal to 120 cal/cm^2 hour (outside the atmosphere) and t is the time in hours. Using Eq. 3 and

integrating Eq. 7 yields

$$I_o^{\,d} = 240\left(\frac{Hs}{15}\sin D \sin L + \frac{12}{\pi}\cos D \cos L \sin H_s\right) \qquad (8)$$

Finally, the hours of sunshine and insolation per month are found, to sufficient accuracy, by multiplying the daily quantities calculated at the 21st of each month, by the number of days in the month, N.

$$S_o = S_o^{\,d}\, N \qquad (9)$$

$$I_o = I_o^{\,d}\, N \qquad (10)$$

These calculations were programmed onto an HP 41 C hand calculator. The program is shown below.

Program on HP 41C calculator with HP 82143A printer calculating I_o and S_o for Eq. (2). The instructions are:

1. Put the number of days in the month into store 01.

2. Put the latitude of the site in decimal degrees into store 09.

3. Put $2\pi n/365$ in decimal degrees into the X register.

4. Execute "QS".

The printer will print numbers in the order:

1. $2\pi n/365$ for the month

2. Latitude of site

3. Number of days in the month

4. S_o

5. I_o

```
I0 ANI 30

I/I0=a+b.30

JULY 29,1983
PRAIA

01♦LBL "QS"
02 PRX
03 SIN
04 [illegible]
05 *
06 STO 08
07 TAN
08 RCL 09
09 PRX
10 TAN
11 *
12 CHS
13 ACOS
14 STO 06
15 RCL 01
16 PRX
17 *
18 7.5
19 /
20 STO 07
21 PRX
22 RCL 06
23 SIN
24 RCL 09
25 COS
26 *
27 RCL 08
28 COS
29 *
30 12
31 *
32 PI
33 /
34 RCL 08
35 SIN
36 RCL 09
37 SIN
38 *
39 RCL 08
40 *
41 15
42
43 +
44 2
45 *
46 [illegible]
47 +
48 RCL
49 *
50 PRX
51 END
```

APPENDIX AB. DUST IN THE ATMOSPHERE

Onyango [8] has shown that a "universal" formula due to Sayigh allows one to calculate global insolation from the daily sunshine duration for over 20 years in East African locations Kenya, Uganda, Tanzania. In addition to sunshine duration the formula requires the maximum daily temperature the relative humidity and the monthly relative humidity factor. He claims good agreement between calculated values and measured values.

In view of the two very distinct seasons of the Sahelian countries, especially Cape Verde, where during the winter months dust is a significant radiation absorbing and scattering entity, one would expect that such a "universal" formula may not be universal but would have to include terms describing the dust content of the air. A good measurement program in Cape Verde could contribute to development of such a formula for relating insolation to sunshine duration including the effects of dust.

APPENDIX B

EVOLUTION OF PETROLEUM PRICES IN CAPE VERDE

C.F. Kooi

Cape Verde Renewable Energy Project (625-0937.03), USAID / Praia

June 13, 1983

I. Petroleum products power pratically all of the modern sector and a considerable part of the traditional sector in the Republic of Cape Verde. It is all imported. No domestic petroleum resources are known and, because of the volcanic nature of the islands, there is little prospect of finding any.

Somewhat more than 30,000 tonnes* per year are used internally. Internal petroleum consumption has been increasing over the past few years as shown in Table I. Re-exported fuels, i.e., for ships and airplanes, are not included in this table.

TABLE I

Internal consumption of all petroleum products in Cape Verde

Year	Consumption (tonnes)
1979	25,637
1980	28,337
1981	30,381
1982	30,472

The products include heavy oil (desalination, electric power), diesel fuel (transportation, electric power, agriculture, construction, pumping, etc.), kerosene (cooking, lighting), liquid petroleum gas, LPG (cooking, lighting), gasoline (transportation, agriculture, etc.).

Prices and import costs of petroleum products are obviously of importance to the Cape Verdean economy. The evolution of petroleum prices is especially important in connection with the economic viability of alternate energy technologies and recurrent costs of A.I.D. projects.

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* Metric tonnes.

II. Evolution of Import Prices of Petroleum Products

The prices in U.S. dollars of petroleum fuels increased by about a factor of ten between 1972 and 1980*. Since 1980 the prices (in dollars) have stabilized and recently they have gone down. OPEC raw petroleum prices, for example, have been recently reduced from about $34 to about $29 per barrel.

Unfortunately, many developing countries, including Cape Verde, have not experienced these price reductions. Their petroleum fuel costs continue to increase. This is shown in Figures 1 and 2. The prices shown in Figure 1 are import prices - before taxes, subsides, and distribution costs are applied. Prices shown in Figure 1 are some during the year, and the data points are arbitrarily placed at June 30 of each year; those of Figure 2 are those of the precise dates indicated.

The effects of the OPEC price increase of 1979 are evident. The prices continued to increase after 1979 even when world export petroleum prices were constant or decreasing. The reason lies in the increasing dollar (U.S.)/escudo (C.V.) ratio, since one must pay for petroleum imports in dollars. The time evolution of this ratio is shown in Figure 3. It has doubled since 1980 and that is enough to produce the import price increases of petroleum products shown in Figure 1 and 2.

Will prices of petroleum products continue to increase for Cape Verde?

The answer depends on so many factors (escudo/dollar ratio, increased oil demand due to increased world-wide economic activity, political and military events in the Middle East, etc.) that it cannot be answered with much confidence. However, since petroleum is a finite resource and world population (and petroleum consumption?) continues to increase one would expect the price of petroleum to increase substantially in the long run. Unfortunately, it is the short term prediction (10 to 15 years) that is needed for estimation of economic viability of alternate energy systems.

III. Implications for Alternate Energies

The economic viability of most alternate energy technologies in Cape Verde is intrinsically related to the prices of petroleum products. Simply put, if oil is cheap alternate energies can't compete, if it is expensive they can. To compare the economics of an alternate energy

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* If adjusted for general inflation it is less than this.

system, such as a photovoltaic water pump, to a conventional petroleum driven system, such as a diesel pump, one calculates the present value of all cash flows over the life of the systems. Since system lifetimes can be 5 to 25 years one must, therefore, predict the prices of everything involved for many years into the future. Petroleum fuels are frequently the largest expense, e.g., about 70 % of all costs in the case of the Mindelo desalination plant*, and the prediction of their future price increases is, therefore, often the most critical input to the economic calculation. Price evolution in the past cannot, of course, tell what will happen in the future, but the large increases experienced by Cape Verde (Fig. 1 and 2) over the past few years warn us against the recent, pervasive, assumption that petroleum prices have stabilized.

Implication A. (Petroleum price escalation rates). In economic comparisons of alternate energy systems with petroleum-fueled energy for Cape Verde, it is wise to assume petroleum fuel price escalation rates that are higher than those that are currently being used elsewhere, especially those used for the U.S.A..

Development and finance organizations provide funding for many energy production and consumption systems in Cape Verde.

This funding is usually applied to the purchase and installation of the system and usually does not include operating costs. When these systems are powered by petroleum based fuel (e.g., desalination plants, city electric power systems) the operating costs over the life of the system can be considerably larger than the initial cost**. These "recurrent" costs are borne by the host country. When petroleum fuel is a major part of the cost and the host country is an oil importer, the major part of the "recurrent" cost is in hard currency foreign exchange. At the Mindelo desalination plant this hard currency foreign exchange cost is about 110 escudos (C.V.) per tonne of water (about 1.60 U.S. dollars today).

---

* Sonia MORAIS, Managing Engineer, Mindelo Desalination Plant.

** For the Mindelo desalination plant the present values of costs over a 20 year plant life are about:

Initial cost (construction, etc.)	18 %
Fuel oil	68 %
Other operating costs	16 %

This partition of costs will change somewhat depending on choices of future price escalation and discount rates.

(Estimates of Cost of Desalinated Sea Water in Cape Verde, USAID/Praia Report, C.F. Kooi, May 16, 1983).

Implication B. (Recurrent Costs). In choosing an energy system one should consider ways to reduce the "recurrent" costs of the system which the host country must usually pay. This is especially important if the "recurrent" costs are in hard currency foreign exchange and if they are the largest part of the total lifetime costs of the system. Alternate energies, such as wind and solar energies which are locally available, should be considered.

Not only is this a heavy burden in terms of hard currency foreign exchange, but fluctuations in internationally traded petroleum prices and in the dollar/escudo exchange rate constitute a substantial risk for the host country. Although nobody expects this risk to be as great as during the last decade* it would still be wise to consider risk avoidance measures when planning new installations. Examples of risk avoidance (or minimization) measures are:

- use a plentiful fossil fuel such as coal
- use a locally available energy source such as wind or solar energy
- stockpile petroleum fuels
- install higher efficiency equipment or processes

Implication C. (Risk Avoidance). When choosing a system that consumes large amounts of energy one should give weight to measures and types of systems that avoid or minimize the risks associated with uncertain future prices of petroleum fuels and uncertain future dollar/escudo exchange rates. The use of non-imported alternate energies such as wind, solar or geothermal is one such risk avoidance measure.

Minimizing the recurrent costs and the risks associated with petroleum fuels will usually, if not always, require a larger initial investment. Straight financial analysis without consideration of these recurrent cost and risk factors may favor a traditional petroleum fueled system. However, consideration of recurrent costs, especially if they are hard currency payments to foreign suppliers, and of risk factors may tip the balance in favor of a system powered by an alternate energy source.**

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* The price of fuel oil at the Mindelo desalination plant increased 22 times since it was opened in 1972 (Sonia MORAIS, Managing Engineer).

** These are, of course, only two factors that go into choosing the system. There is a multitude of other considerations such as local job creation, risk of physical interruption of oil supply, uncertainties and risks associated with new alternate energy technologies, uncertainties concerning the future price evolution of alternate energy components (such as photovoltaic panels), personnel skill requirements, etc..

IV. Acknowledgements

I wish to thank the following people for assistance and for providing information:

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José Gomes, D.G.I.E., Praia
Sonia Morais, ELECTRA, Mindelo
Martinho Ramos, ELECTRA, Mindelo
Manuel Monteiro, ELECTRA, Mindelo
Eurico Pascoal Almeida, ELECTRA, Mindelo
Rui S. Lopes dos Santos, ENACOL, Mindelo

V. Glossary

C.D.T.C.	Centro de Documentaçao Técnica e Científica
D.G.I.E.	Direcção-Geral de Indústria e Energia
ELECTRA	Empresa Pública de Electricidade e Água
ENACOL	Empresa Nacional de Combustíveis

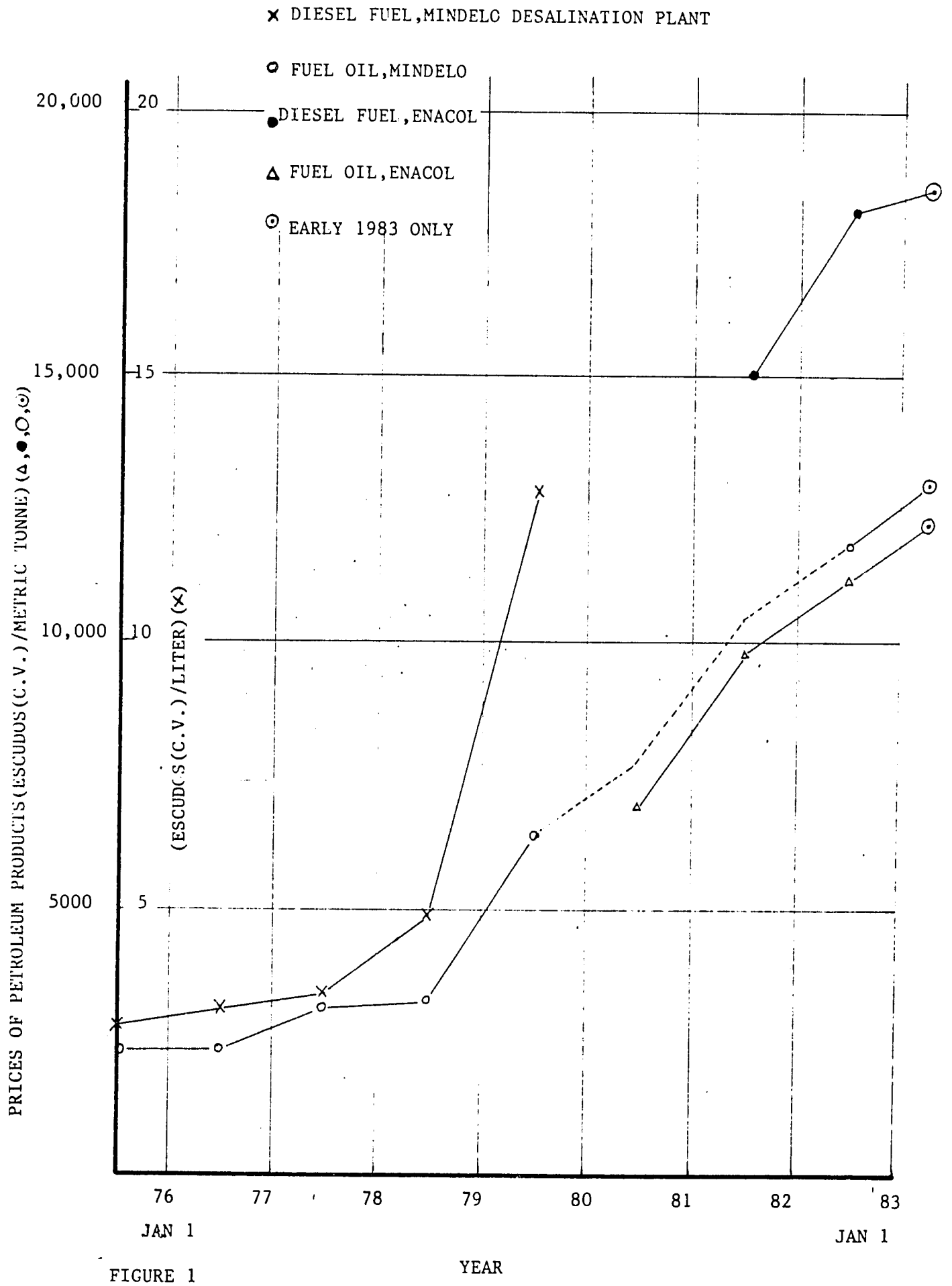
× DIESEL FUEL,MINDELO DESALINATION PLANT
○ FUEL OIL,MINDELO
● DIESEL FUEL,ENACOL
△ FUEL OIL,ENACOL
⊙ EARLY 1983 ONLY
20,000
15,000
10,000
5000
20
15
10
5
PRICES OF PETROLEUM PRODUCTS(ESCUDOS(C.V.)/METRIC TONNE)(△,●,○,⊙)
(ESCUDOS(C.V.)/LITER)(×)
76
77
78
79
80
81
82
83
JAN 1
JAN 1
YEAR

FIGURE 1

118

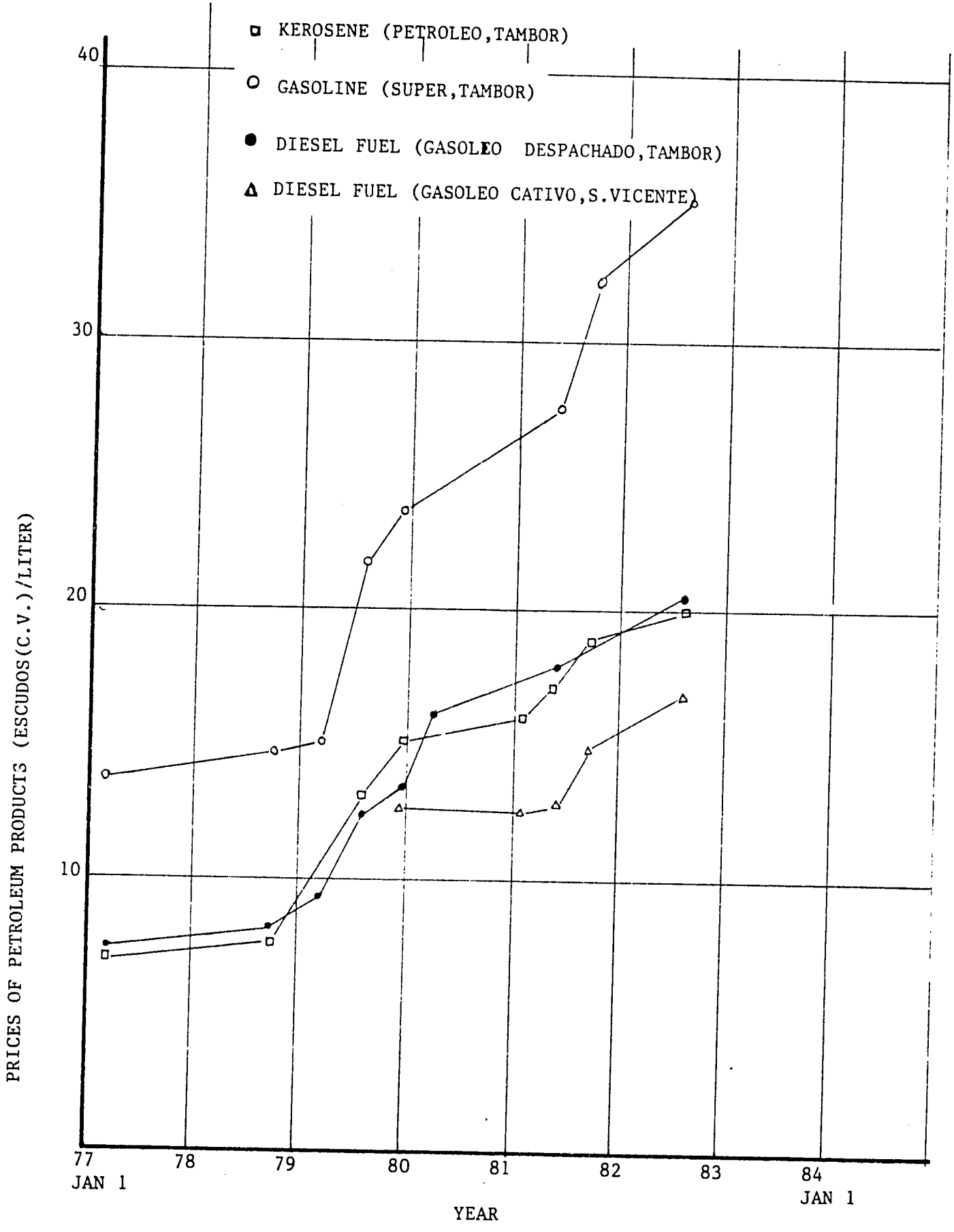
KEROSENE (PETROLEO,TAMBOR)
GASOLINE (SUPER,TAMBOR)
DIESEL FUEL (GASOLEO DESPACHADO,TAMBOR)
DIESEL FUEL (GASOLEO CATIVO,S.VICENTE)
40
30
20
10
PRICES OF PETROLEUM PRODUCTS (ESCUDOS(C.V.)/LITER)
77
JAN 1
78
79
80
81
82
83
84
JAN 1
YEAR

FIGURE 2

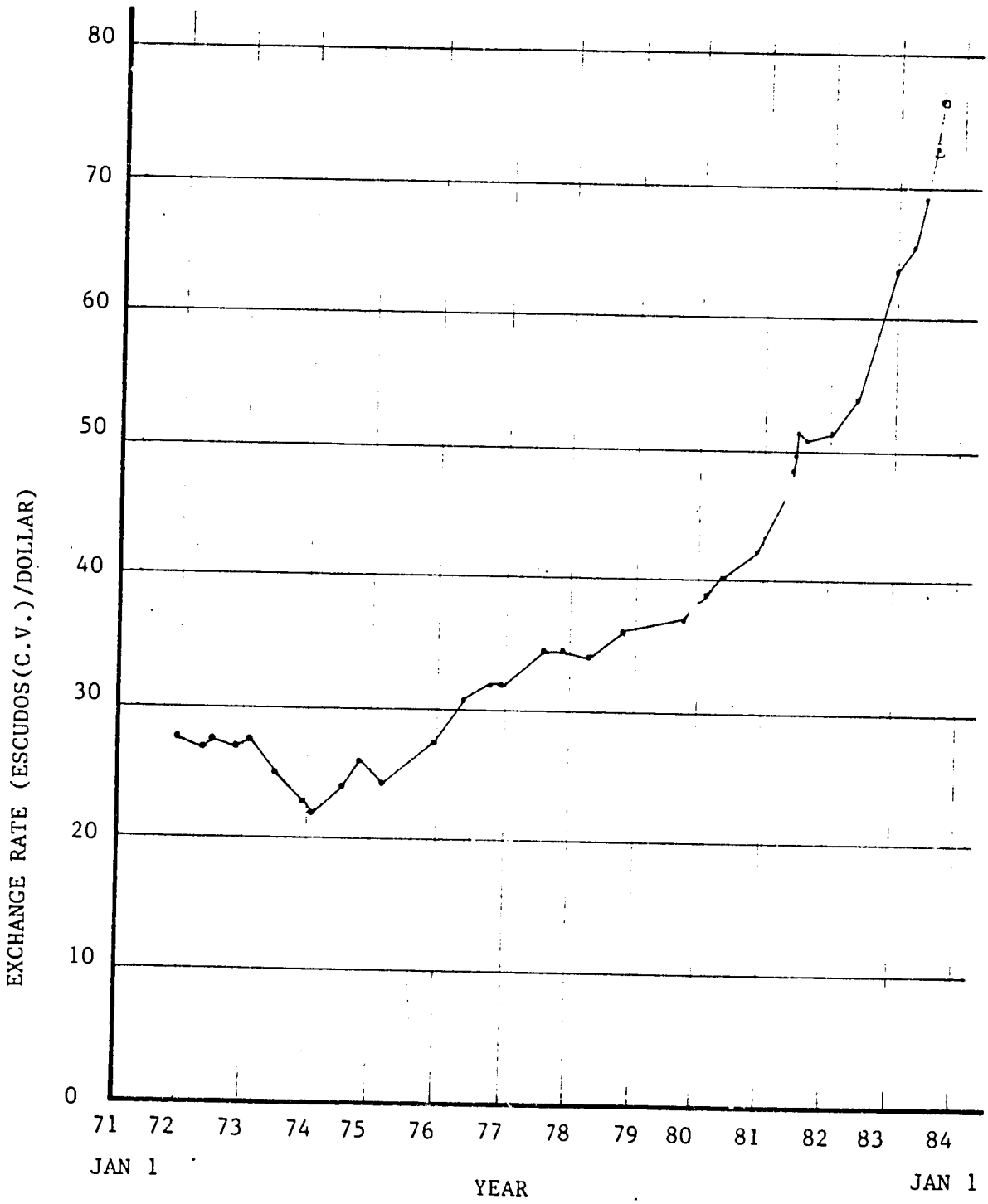
80
70
60
50
40
30
20
10
0
EXCHANGE RATE (ESCUDOS(C.V.)/DOLLAR)
71
72
73
74
75
76
77
78
79
80
81
82
83
84
JAN 1
YEAR
JAN 1

FIGURE 3

120

FIGURE CAPTIONS

1. Evolution of prices of some petroleum products at Mindelo, São Vicente. These prices do not include any taxes, subsidies or costs of retail sales and distribution. They are prices which occurred during the year and are arbitrarily plotted at June 30 of each year. Data were obtained from ENACOL and ELECTRA, S. Vicente.

2. Evolution of prices of some petroleum products in Cape Verde. The Gasóleo Cativo is dedicated to fueling the electric power station and desalination plant at Mindelo and does not include taxes, subsidies or retail transport and sales costs. The prices of the other products include these costs. "Tambor" refers to sales in 200 liter containers, the price at the pump being slightly higher. Data were obtained from D.G.I.E., C.D.T.C., and the Boletim Oficial da República de Cabo Verde.

3. Evolution of the Cape Verdean escudo: United States dollar exchange rate. Data from Boletim Oficial da República de Cabo Verde.

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Appendix C. CALCULATION OF THE PRESENT VALUE OF A TIME SERIES OF CASH FLOWS.

The present value of a series of annual cash flows is:

$$\text{Present value} = \sum_{n=1}^{N} A_n \left(\frac{1}{1+R}\right)^n \qquad (1)$$

where A is the cash flow in year n and R is the discount rate (or expected return on investment). N is the year of the last cash flow. If the annual cash flow is a constant times a price escalation factor this can be written as:

$$\text{Present value} = A \sum_{n=1}^{N} \left(\frac{1+I}{1+R}\right)^n \qquad (2)$$

where A is the cost of the quantity during the first year and I is its annual price escalation rate. I can be the general inflation rate, fuel price escalation rate, etc. Equation (2) can be written

$$\text{Present value} = A \left(\frac{1-(1+R')^{-N}}{R'}\right) = A \times PV\,(N,I,R) \qquad (3)$$

where $R' = \frac{R-I}{1+I}$ and $PV\,(N,I,R)$ = the present value factor.

If a cash flow occurs only at year n its present value is

$$\text{Present value} = A_n\,(1+R')^{-n} = A_n\,P\,(n,\ I,\ R)$$

where $P\,(n,\ I,\ R)$ is defined as the present value factor for one cash flow at year n.

Appendix D : MODEL FOR A SOLAR POND DEVELOPMENT PROJECT

A. Title page

Project title: "Salt Gradient Solar Ponds for Cape Verdean Applications".

Duration of Project: Three years.

Total Cost of Project: $128,000 external funding. The Government of Cape Verde will contribute salaries (except for foreign consultants), laboratory space and equipment, and space for building the solar pond. Its contribution is valued at 3,600,000 CVE.

Investigators:
To be named by I.N.I.T.

Technical Assistants:
To be selected.

Location of Project: The project will be located and carried out at Praia, Republic of Cape Verde.

B. Project Objective

The objective of the project is to gain experience in construction and operation of salt gradient solar ponds and to determine their operating characteristics in the Cape Verdean environment in preparation for large scale use in generation of electrical power and production of desalinated water.

C. Technical Work Plan

As we have seen in Section VII-2 ponds have many advantages over other low-temperature solar heat collectors. Furthermore, they are particularly attractive for applications at low-latitudes and under coastal Sahelian conditions. The Work Plan is designed to study, verify, and capitalize on these advantages. This will be done by constructing a pond, operating it, measuring its properties and behavior, comparing to and developing theory as needed, and finally withdrawing heat from the pond for a first application. This first application will be the generation of mechanical power.

Construction of Solar Pond:

The pond will be circular with an area of 200 m^2. It will be 2 to 3 meters deep. The lining will be plastic such as EPDM, HDPE, or

CPE [1]. The salt will be NaCl, produced locally. The sides may or may not be insulated and this choice also will be made after further study. The budget allows for these choices.

The pond will be located at a suitable site in or near Praia so that continuous attention can be given to it by project personnel.

The construction will be carried out by the personnel of I.N.I.T. with contracted skills as required. One of the technical assistant visits will coincide with the construction.

Measurement and Comparison to Theory:
Approximately 100 measurements will be taken on a scheduled basis. This will be done by means of the appropriate sensors, scanned, reduced and stored by a Hewlett-Packard HP-IB or similar system. This system will consist of an HP 9825A calculator, scanner, voltmeter, plotter, printer and disc drive or equivalent system.
The measurements taken will be
1. Solar radiation flux density (W/m^2) as function of depth. This will be done with a LI-COR, or equivalent, sensor produced for use in salt water. This will produce the values of h(z), needed for calculation of pond efficiency.
2. Temperature of water as a function of depth; to be done with a stainless steel sheathed thermocouple. This will produce data needed for determination of stability, zone structure, and efficiency.
3. Salinity will be measured as a function of depth. This will be done by sampling and weighing, and by means of a Beckman electrodeless conductivity probe (mutual inductance type). This information is needed for zone stability checks and for comparing gradient zone size with theory.
4. Ground temperature measurements will be made at 50 to 100 points by means of the thermocouples. This will allow calculation of heat loss to the ground in order to correct the first order efficiency expressions which do not include ground losses. Comparison will also be made to the ground loss calculations of Hull, et al., [2].
5. It is expected that direct and diffuse insolation measurements will be made by I.N.I.T. at or near the pond location.
6. Wind speed above the pond surface with a recording anemometer will be measured. This is needed to compare measured thickness of the upper convective zone with the theory of Cha, et al., [3].

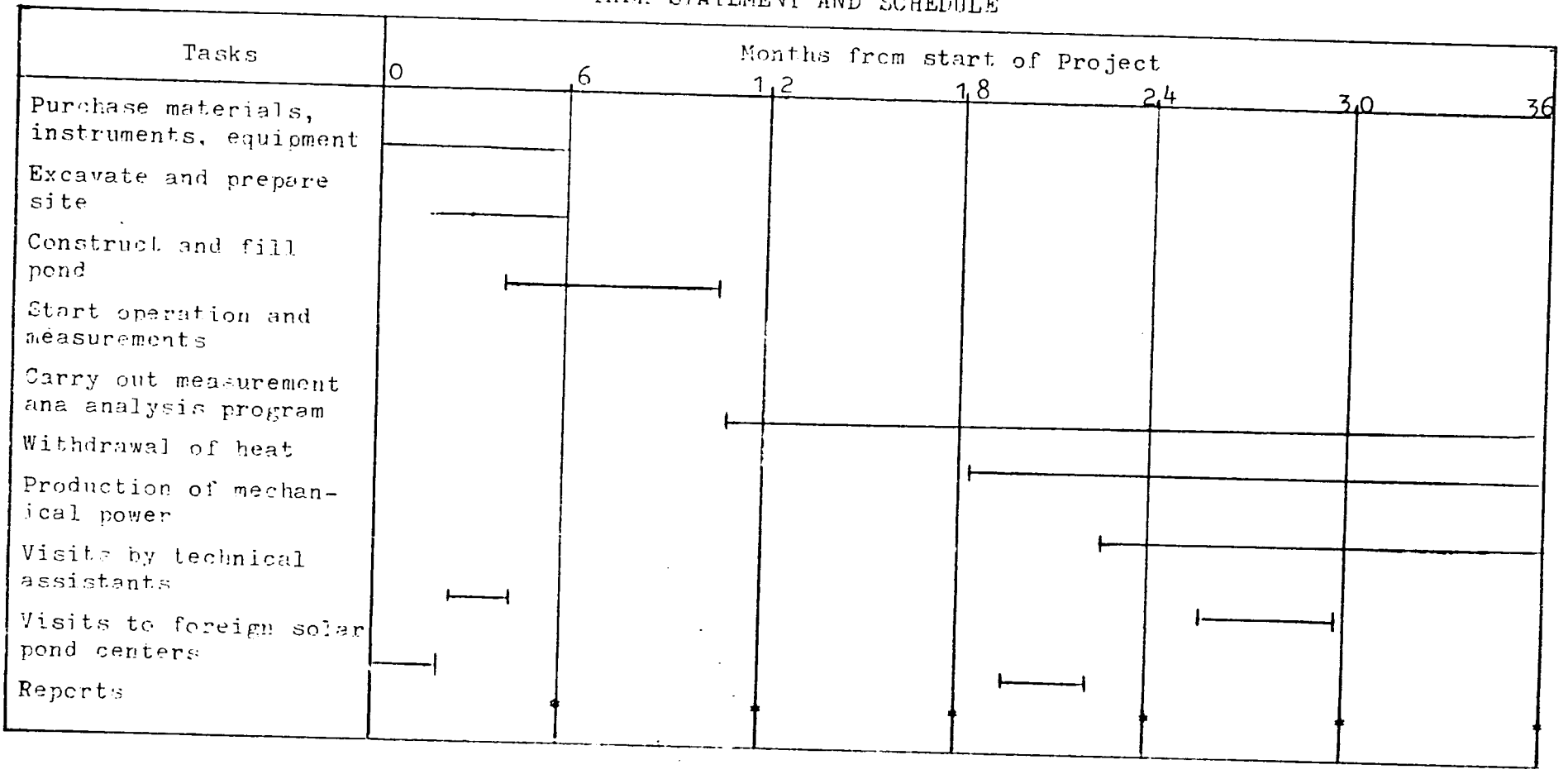
It is expected that this program of measurements and comparison to theory will continue for at least a year and a half under this project and much longer under subsequent financing. The results to be expected are simply the realization of the augmented performance that one expects in a climate and location such as Cape Verde - thinner upper convection zone, more nearly steady state operation, better utilization of diffuse radiation and higher efficiency - which one does not expect in higher-latitude locations.

Use of Pond Heat:

Withdrawal of heat and measurement of the quantity withdrawn will be started after one and a half years of operation. The withdrawal mechanism will be two diffusers, an inlet and an outlet, connected to an exterral heat exchanger. This will provide experience in heat withdrawal techniques and provide heat for the first applications.

It is planned that the first application will be generation of mechanical power by use of the SOFRETES motor at Achada São Filipe, which will be transported to the pond site.

TASK STATEMENT AND SCHEDULE



D. MODEL BUDGET (numbers in USD unless specified otherwise)

Budget *

The budget is broken down into funds provided by the Donor and by the Government of Cape Verde. It is further broken down into moneys spent in Cape Verde and those spent abroad.

A. Funds provided by Donor

Item	Procured in Cape Verde	Procured abroad
1. Solar pond construction costs:		
Earth moving (1000 m^3 at 200 CVE/m^3)	200,000 CVE	
Pond liner (300 m^2 at 10 USD/m^2)		3,000
Salt (100 tonnes at 4000 CVE/tonne)	400,000 CVE	
Heat exchangers, pumps, piping, diffusers		4,000
Instrumentation structures and installation	100,000 CVE	
Wave supressors	50,000 CVE	
Miscellaneous and inflation (15%)	100,000 CVE	1,000
Subtotals	850,000 CVE	8,000
2. Instrumentation and control:		
Pyranometer (2 underwater, 1 above with shadow-bar)		8,000
Control; data logging, treatment and storage (Hewlett-Packard-1 B system with HP-9825 calculator, scanner, voltmeter, disc drive, plotter, printer)		35,000
Instruments for measurement of water properties (salinity, acidity, algae control, turbidity)		2,000
Flowmeter, thermocouples, anemometer		3,000
Strip chart recorder		4,000
Miscellaneous and inflation (15%)		7,000
Subtotals		59,000
3. Transport and adaptation of SOFRETES motor and pump:		
Transport	5,000 CVE	
Material and parts	200,000 CVE	3,000
Labor	50,000 CVE	
Professional personnel	50,000 CVE	
Subtotals	305,000 CVE	3,000

* Currency conversion made at 70 CVE = 1 USD

Item	Procured in Cape Verde	Procured abroad
4. Shipping, procurement expense, taxes, duties		
Items procured abroad (17%)		12,000
Items procured in Cape Verde (7%)	85,000 CVE	
5. Technical assistance and visit to solar pond centers		
Salary (80 working days x 250 USD/day)		20,000
Per diem (100 days x 40/day)		4,000
Air tickets (2 U.S.A. - Cape Verde)		5,000
Two trips abroad from Cape Verde:		
Air tickets		5,500
Per diem (100 days at 75 USD/day)		7,500
Subtotal		41,000
Totals	1,240,000 CVE	123,000
Total contribution of AID	141,000 USD	

B. Funds provided by Government of Cape Verde

Item		Procured in Cape Verde	Procured abroad
Chief of project	based on 30% of working time during the three years of project duration	1,200,000 CVE	
Project assistant		600,000 CVE	
Research technician		400,000 CVE	
Equipment and workshop facilities		400,000 CVE	
Land (500 square meters)		400,000 CVE	
Subtotal		3,000,000 CVE	
Project Administration (20 %)		600,000 CVE	
		3,600,000 CVE	
Total contribution of Cape Verde		51,000 USD	

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References

1. R. Peter Fynn and Ted H. Short, "Solar Ponds - A Basic Manual", The Ohio Agricultural Research and Development Center, Wooster, Ohio 44691, U.S.A. (1983).

2. T.R. Hull, Y.S. Cha, W.T. Sha, and W.W. Schertz. Proceedings AS/ISES, June 1-5 (1982). Proceedings to be published by the International Solar Energy Society.

3. Y.S. Cha, W.T. Sha, and W.W. Schertz. "Modelling of the Surface Convective Layer of Salt Gradient Solar Ponds", 15th IECEC Meeting, Atlanta, August 9-14 (1981).

APPENDIX E. MODEL FOR AN IMPROVED COOKING TECHNOLOGY PROJECT

Objectives: (1) To reduce consumption of wood, vegetable matter, etc. so as to promote reforestation, erosion control, environmental improvement, and release vegetable matter for other uses.
(2) To reduce labor and expense of obtaining cooking fuels.

Method: Develop, test and disseminate improved stoves and cooking methods. These may be massive stone stoves, low-mass fired-clay stoves, pressure cookers, insulated cooking ("straw") boxes, and other techniques if found to be promising.

Plan: The program will begin with a preliminary experimentation stage in which two types of stove, stone and fired-clay, will be constructed and tested. Pressure cookers and "straw" boxes will also be tested. This will be done at an M.D.R. extension center, and cooperating households in the neighborhood. In this initial phase sufficient knowledge will be gained and sufficient skills will be developed to start introducing the improvements into households in the neighborhood other than those cooperating households that were involved in Phase I. This second phase (II) will incorporate field testing, instruction in stove use and cooking methods(pressure cookers, straw boxes), do-it-yourself construction, etc.. Fast and appropriate response to feedback from the field will be the salient feature of Phase II.

Implementation: The program will be carried out by an appropriate organization of the Government of Cape Verde. A full time program supervisor and two halftime assistants will be assigned to the program in the beginning. A technical advisor with experience in introducing improved cooking methods in Africa will devote 4 person months to the program. Funding for materials and equipment for Phase I of 250,000 CVE will be provided.

Phase I:	1 year	
	1 supervisor	12 pm
	1 assistant-construction	6 pm
	1 assistant-user	6 pm
	1 technical advisor (foreign)	3 pm
Phase II:	2 years	
	1 supervisor	24 pm
	1 assistant-constructor	24 pm
	1 assistant-constructor, user	24 pm
	1 technical advisor (foreign)	4 pm

The personnel and funding levels for Phase I must be assured at Program Commencement. Those for Phase II will change depending on the results of Phase I.

Equipment and materials for Phase I
To be purchased in Cape Verde

Item No.	Articles or Services	Quantity	Unit price Cost	Unit price Per	Amount in CVE
1.	Stove building tools (stone working, etc.) each set consisting of shovel, hoe, pick, hammers, travel, etc.)	5	2000	set	10,000
2.	Cement (bag)	20	350	bag	7,200
3.	Iron bar (approx. 3/4" dia.)	100	150	m	15,000
4.	Cooking pots and utensils (various)	50	300	ea	15,000
5.	Iron sheet (approx. 1/2" thick)	15	500	m2	7,500
6.	Miscellaneous material (screws, nuts & bolts, etc.)				10,000
7.	Equipment for clay construction and firing				50,000
	CONDITIONS OF PAYMENT: Funds to the Project Leader who will purchase items locally and account for purchases.				
	Total				114,700 (1640 USD)

Equipment and materials for Phase I
To be purchased abroad

Item No.	Articles or Services	Quantity	Unit price in USD	Amount in USD
1.	Multimeter with leads, batteries, similar to Fluke professional models which are - portable - measure R,V,I (a.c. & d.c.) over standard ranges - have proper reference for thermocouple use so that temperature can be measured	2	350	700
2.	Immersible thermocouples for temperature range 0-120 °C. Must have corrosion proof jacket suitable for soft or salt water. Must work with item 1	5	120	600
3.	Balance for field use Approximate range: 100 grams to 50 kilograms Accuracy: ± 50 grams Portable: Spring type acceptable if required accuracy can be attained	2	200	400
4.	One liter calibrated stainless steel measurement containers. Accuracy of calibration: 10 cl.	2	8	16
5.	Pressure cookers of various types	10	40	400
	Subtotal			2.116
	Procurement, shipping, insurance (60 %)			1.270
				3.386

List. 3. Central Laboratory Calibration, Repair, Data Handling Equipment

Item No.	Articles	Quantity	Unit price Cost	per	Amount in USD
1.	Desk computer	1	10,000	ea	10,000
2.	Repair and calibration instruments	1	10,000	set	10,000
3.	Files, office equipment	1	5,000	set	5,000
	Subtotal				25,000
	Shipping, packing, purchasing (60 %)				15,000
	Total				40,000

For five field stations and 2 sets of spare field stations the total equipment cost would be:

List 1	25,920.
List 2 (x7)	88,480.
List 3	40,000.
Total (all equipment)	154,400. USD

Travel and Technical Advisor Costs - Phase I

	Cost (USD)
Travel: Supervisor to travel to improved stove projects in West Africa for one month.	
per diem	2,400
air tickets	1,000
Air ticket, foreign technical advisor	2,000
Per diem and salary, foreign technical advisor	18,000
Total	24,000

Facilities

Space for outdoor construction and testing (500 m2)	not determined
Indoor space for storage of equipment (20 m2)	not determined

Salaries

Supervisor	not determined
Assistant-construction	not determined
Assistant-user	not determined

Transportation

Transportation between Praia and Rural Extension Center	not determined

APPENDIX F. EQUIPMENT FOR INSOLATION MEASUREMENT PROGRAM

The insolation measurement equipment at the central laboratory, Praia, should be capable of continuously recording, and integrating over the hour and day, the global and diffuse insolation. Suitable equipment for this is shown in List 1.

List 1. Central Laboratory Measurement Equipment

Item No.	Articles	Quantity	Unit price Cost	Per	Amount in USD
1.	Thermopile pyranometer similar to part No. R413, p. 156 (Weathermeasure catalogue) or to Eppley precision models)	2	1,400.	ea	2,800.
2.	Recorder with integrator similar to model R12V-I-INT (Weathermeasure) to function with item 1	2	5,100.	ea	10,220.
3.	Cable similar to Weathermeasure part R413-20 to connect item 1 and 2. Fifty (50) foot length	2	50.	ea	100.
4.	Shadow bar for diffuse insolation	1	1,200.	ea	1,200.
5.	Chart similar to CET 12 V-1-INT/100, p. 164 Weathermeasure catalogue, for item 2	100	9.	ea	900.
6.	Accessory sets for recorders (ink, pens, etc.)	2	90.	ea	180.
7.	Campbell-Stokes sunshine duration measurement and charts	1	800.	ea	800.
	Subtotal				16,200
	Shipping, packing, purchasing (60%)				9,720
	Total				25,920

For each field station one should have the equipment or equivalent shown in List 2. In addition one or two complete extra sets of List 2 should be on hand for replacement, repair and calibration needs.

List 2. Field stations Measurement Equipment

Item No.	Articles	Quantity	Unit price Cost	per	Amount in USD
1.	Thermopile pyranometer (same as 1 of List 1)	2	1,400.	ea	2,800.
2.	Electronic integrator for daily totals	2	1,500.	ea	3,000.
3.	Shadow bar (same as 4 of List 1)	1	1,200.	ea	1,200.
4.	Cable (same as List 1)	2	50.	ea	100.
5.	Campbell-Stokes (same as 7 of List 1)	1	800.	ea	800.
	Subtotal				7,900.
	Shipping, packing, purchasing (60 %)				4,740.
	Total				12,640.

Additionally, the central laboratory must provide for calibration and repair and for data collection, reduction, storage and reporting. A possible list of such equipment is given in List 3.

List 3. Central Laboratory Calibration, Repair, Data Handling Equipment

Item No.	Articles	Quantity	Unit price		Amount in USD
			Cost	per	
1	Desk computer	1	10,000	ea	10,000
2	Repair and calibration instruments	1	10,000	set	10,000
3.	Files, office equipment	1	5,000	set	5,000
	Subtotal				25,000
	Shipping, packing, purchasing (60 %)				15,000
	Total				40,000

For five field stations and 2 sets of spare field stations the total equipment cost would be:

List 1	25,920.
List 2 (x 7)	88,480.
List 3	40,000.
Total (all equipment)	154,400. USD

APPENDIX G. IMPORT COSTS VERSUS IN-COUNTRY COSTS OF A FEW RENEWABLE ENERGY SYSTEMS.

When considering introduction of renewable energies the question of production of equipment and materials in the country is of great importance. It is obviously an advantage if a significant portion of the equipment can be manufactured, or at least assembled, in the country and even better if the basic materials can be found locally. We shall, in the following, make a few estimates of portions of different systems which could be manufactured or assembled in the country.

Photovoltaic systems:

Currently costs run about 30,000 USD for a one kilowatt (peak) system. The photovoltaic panels are 10,000 USD at the factory. The remaining 20,000 USD is the cost of the BOS (Balance of System). A large part of this is installation and assembly. We do not know much can be done locally but the opportunities for assembling and installation are there. At the moment the costs are largely import costs. In the future if all assembly and installation were done in the country one could expend perhaps 20 % of the costs in the country.

Salt gradient solar ponds electricity generating systems:

Consider a solar pond of size 1 square kilometer with a rated electrical power output of 5 MW. Following section VII-2, and breaking the cost into imported and local costs we have,

	Imported	Local
Pond liner (6 USD/m2 x 1.1×10^5 m^2)	6,600,000 USD	
Salt (0.7 tonne/m2 x 10^6 m^2 x 20 USD/tonne)		14,000,000 USD
Earth moving (2 USD/m3 x 10^6 m^3)		2,000,000
Materials, pipes, etc.	500,000	
Labor		1,000,000
Power plant labor		1,000,000
Power plant equipment	6,500,000	
	13,600,000 USD	18,000,000

Import costs are 43 % of the total, local costs are 57 % of the total.

Water pumping windmills:

Water pumping windmills can be constructed almost entirely in Cape Verde. In fact JOTENAVE is building windmills for the USAID Renewable Energy Project that are constructed, except for purchased bearings, entirely in Mindelo. That includes casting and machining gears and making the

brass pumps. Therefore the only imported costs are for steel, brass, nuts, bolts, bearings, etc. One would have to ask JOTENAVE for an accurate cost breakdown. However, one might guess that about 10 % of the cost would apply to the imported parts.

Wind electric generation:

Due to the small market it is unlikely that wind electric generators and auxiliary equipment will be manufactured in the country. Therefore, the local cost component will be limited to perhaps tower construction and wind machine installation. This could be 20 % of the costs.

These results are summarized below:

	Import costs	In country costs
Wind water pumps (guessed)	10 %	90 %
Salt gradient solar pond electric system	43 %	57 %
Wind electric generators (guessed)	80 %	20 %
Photovoltaic systems (present)	95 %	5 %
Photovoltaic systems (future, guessed)	80 %	20 %

We apologize for the "guessed" category. However, it is useful for comparison with those items which are better know. It is evident that wind water pumping has the lowest percentage of import costs followed by solar pond electricity generators and finally the poorest will be wind electric and photovoltaic systems.