DOE/ET/20279--T15

DOE/ET/20279--T15

DE90 008431

PHOTOVOLTAIC SYSTEMS FOR EXPORT APPLICATION

INFORMAL REPORT

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Submitted to

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77 Massachusetts Avenue
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(under contract
DOE-AC02-76ET20279)

January 31, 1988
Revised June 30, 1988

1. PROJECT OVERVIEW

One approach to improving the competitiveness of photovoltaic systems is the development of designs specifically for export applications. In other words, where is it appropriate in a system design to incorporate components manufactured and/or assembled in the receiving country in order to improve the balance of payments for that country and to increase photovoltaic exports from the U.S.? What appears to be needed is a systematic method of evaluating the potential for export from the U.S. of PV systems for various applications in different countries. Development of such a method was the goal of this project.

This report summarizes the work on the project. In particular, this overview section includes a brief summary of the methodology and findings of the project. The project was divided into four tasks: (1) review current system export practice; (2) select promising export regions; (3) survey resources and markets in a designated country; and (4) develop a system design criteria and method. The following chapters of the report contains more detailed information on these tasks.

Most of the information on the current export practice was obtained through a telephone/mail survey of all known PV module/system manufacturers in the US and in appropriate developing countries. Among the findings in the survey is that the most frequently mentioned application for PV systems is water pumping. The chief finding to date is that the majority of manufacturers lie at two poles: either they manufacture complete stand-alone PV systems for export or they build and export equipment for the manufacture of PV modules. Part of the remainder of this study was devoted to the development of a method to find out if there is an optimal mix of design, manufacture, installation, and maintenance both here and abroad. Section 2 contains a summary of the results of the current practice survey.

For the selection of the promising export region, a matrix of relevant parameters associated with each country in the Third World was developed. Parameters such as gross national product (GNP), degree of electrification, climate, and solar insolation were taken into account. On the basis of several of these parameters, a selection of a country for further study was made in order to focus the project: Nigeria. A summary of the country selection process is included in Section 3.

A typical PV system type was also selected in order to focus the scope of the project and to test the methodology being developed. Water pumping was chosen for several reasons:

1. It was the most frequently mentioned application by PV manufacturers. See Section 2 for details.
2. The need for clean water on humanitarian grounds is clearly evident. There are "nearly one billion people living in the rural areas of developing countries ... without access to a safe and reliable supply of water" [Meridian Corporation, 1987a] .
3. There appears to be a huge market potential, from an economic point of view.
4. There is some literature available on the design of water pumping systems [e.g., Sandia National Laboratories, 1987; Matlin, 1986; Intermediate Technology Power Ltd., 1984].

The survey of resource and market potential in the selected country indicated a significant groundwater and surface resource, solar insolation resource, and need for clean drinking water and for irrigation water. The manufacturing capability of Nigeria is increasing and appears adequate to produce many of the components of a PV water pumping system. It was very difficult to obtain economic information from Nigeria. Some estimates of the available village income that typically might be spent on drinking water were made. More details are provided in Chapters 4 and 5.

For the development of export design criteria and design method, an expert systems approach was utilized. The design criteria chosen was minimum initial cost of the entire PV system, including pump and water storage. A prototype optimal design algorithm was implemented with an expert systems shell for a stand-alone drinking water system. In the design method, three basic steps are implemented: (1) the appropriate pump type is chosen based on inputs of well depth and daily volume of water needed, (2) the least-cost system components are chosen based on estimated cost inputs for each imported and each locally-produced component, and then (3) the least-cost combination of array size and water storage volume is computed for a given loss-of-load probability, based on the relative array-related and storage-related costs computed in step 2 and based on the input of solar average horizontal insolation information. This expert systems approach appears to be very promising, and the microcomputer program developed here can be relatively easily expanded to include other more detailed design decisions, constraints, and cost information for Nigeria and other countries. This optimal design method is described in Chapter 6.

The results of using the expert systems design method are presented in Chapter 7. Based on the available cost estimates for the PV system components (some of which have considerable uncertainty associated with them), our optimal typical PV system would be made locally except for the wafers, pumps, and maximum power tracker for a total cost of roughly US $7700. Approximately one-half of that amount would remain in the local country. The array size would be 580 watts peak, and the water storage would 54 cubic meters. The well cost for the 41 meter hole we estimate at roughly $12500. This total estimated initial cost and the system lifetime costs, such as interest, maintenance, pump replacement (which are discussed in Chapter 7), are considerably below the estimated portion of village income available for water costs for the 300 people the well would service.

We identify two major conclusions:

(1) The overall expert systems design optimization method developed in this study appears promising for applications in other similar feasibility-type studies and for actual designs of PV stand-alone systems (of varying types and for various countries).

(2) Based on the data available, PV drinking water pumping systems appear to be within economic reach of villages in dry northern regions in Nigeria. The most cost-effective design would utilize PV cells, modules, array structure, and water storage tanks produced in Nigeria with local labor.

Additional discussion and conclusions are presented in Chapter 8.

2. CURRENT PRACTICE

2.1 Current Practice of U.S. Manufacturers

Photovoltaic systems are currently being produced and sold by U.S. manufacturers for a wide variety of applications in many different countries. Current applications include systems for water pumping for both drinking and irrigation, lighting, refrigeration, navigational aids, communications, and remote general power systems.

Information on the current practice of U.S. manufacturers was obtained from representatives of the World Bank, the U.S. Agency for International Development, the Sandia Laboratory Photovoltaics Design Assistance Center, and the literature [e.g., Flavin, 1986; Eskenazi, 1986; Meridian, 1987a; Jacobson, 1980; Sandia National Laboratories, 1987; Matlin, 1986; Intermediate Technology Power Ltd., 1984].

Results of the Telephone Survey

Important information on current practice was obtained directly from the manufacturers by means of a telephone survey. During July and August, 1987, we contacted all the U.S. photovoltaic manufacturers listed in Refs. Solar Energy Industries Assn., 1987 and "PV Yellow Pages", 1987 in order to obtain up-to-date information about their current photovoltaic export applications. Fifteen out of eighteen companies answered at least some of the questions. Companies were assured that no names would be published and that no single set of questionnaire responses would appear in the final report. The results are summarized below. There were three main subject areas in the questionnaire: stand-alone PV systems for export; PV manufacturing equipment, and marketing and financing.
[The complete questionnaire and detailed responses of the telephone survey can be found in Appendix A.]

2.1.1 PV Stand-Alone Systems and/or Components

Most of the companies (eleven out of fifteen) make and sell PV water pumping systems.

The next most common application areas listed were: lighting (7 out of 15), communication (5), and stand-alone generators (4). Even though water pumping was listed most frequently for present application, rural electrification was given most frequently for business growth areas (although by only 4 out of 15). Consumer products, utilities, and telecommunications were each given twice.

About one quarter of the companies think that the Third World is a potential business growth area for PV stand-alone systems.

It appears as though most U.S. companies want to have every component of a PV system made in the U.S. and to ship the whole system in a package to the buyer (5 out of 9). Only four out of nine of the participating companies try to use parts the receiving country can produce. It appears that at least some U.S. manufacturers do not think that these foreign parts are of sufficiently good quality to use them in a system without fear of failure.

The method of shipping of the components usually depends on the needs of the customer, but it is usually by ship in containers. As far as we know from the answers, to ship by air is approximately ten times as expensive as to ship on the sea.

Usually the receiving country supplies the local labor to assemble, install, and maintain the system. Most of the time these local workers are educated by the PV system manufacturers when the first shipment arrives there.

The usual warranty for PV stand-alone systems or components is between 1 and 5 years.

The PV systems manufactured by the companies participating in our telephone survey were mostly financed by the receiving country's government or by different international organizations.

From the answers given to the question about the approximate cost of the different systems, we could not obtain even an average price.

On average about half of the companies use foreign agents, distributors, or trading companies; the other half does not use local assistance of this type.

In answer to a question about the foreign competition, only two companies out of fifteen state that there is none at all. But one half says that Japan is a serious contender, and there is some competition from some European countries (mostly England and Germany) and Australia. Among the developing countries, India appears to be the only competitor in flat plate manufacturing in the future.

2.1.2 Manufacturing Equipment

This set of questions was answered only by 8 companies, as the others do not deal with PV manufacturing equipment, only with stand-alone PV systems.

All of the 8 companies sell whole turn-key systems, and the most common size (mentioned by one half) is a system capable of producing at least 1 MW/year.

The answer to the question about the manufacturing components provided by local (in the receiving country) suppliers are very different, as they were to a similar question in section 2.1.1 (PV stand-alone system components). There are some companies that use locally produced equipment, while there are others who do not even try them (usually because of the poor quality and unavailability).

The manufacturing systems are mostly installed by the manufacturer, but in some cases (e.g., if it is not the first system of the same kind), the receiving country does it. Based upon this survey, the maintenance work can be done either by the owner or the manufacturer.

In the operation of the PV manufacturing systems, the material of the cells is usually amorphous silicon (50%). The cell efficiency varies between 5 and 17%, while the price is 3-5 $/W (peak).

From the answers of all 8 companies, the manufacturing systems were financed by the local (receiving country's) government, but there were some companies who dealt with private enterprises as well during selling their systems.

On the top of the list of foreign competition is Japan again, as in the case of PV stand-alone systems (and components). Other countries mentioned in these answers as competitors were England and Germany.

2.1.3 Marketing and Financial Issues

Most of the systems produced by 14 companies were sold in India and China, while the remaining systems were sold to various countries scattered throughout the world. The opinion about overseas markets was usually that the major market was in the developing countries (mostly in Africa and in the Far/Middle East).

The customers were typically local/national governments or private enterprises. There was U.S. government involvement only in 3 companies' (23%) businesses, and there were other kinds of involvements (international organizations) in 4 cases out of 13 (31%).

Typical replies as to the estimation of the unserved market were "huge potential", and "Everything we can make we can sell."

Most of the companies (11 out of 14) have performed some kind of feasibility studies or life-cycle cost comparisons as part of their sales effort, but these studies are usually confidential and were not furnished to us.

Most of the companies (8 out of 14) encounter some kind of trade barriers.

2.2 Current Practice of Foreign Photovoltaic Manufacturers

In order to develop a new export design criteria we have to get information about the current practice of the foreign manufacturers too. From our perspective one of the major questions is where could we apply the products of the receiving countries into a U.S. made system. Do their PV products have good quality? Are the available labor forces well trained enough to install and/or maintain the photovoltaic systems? Do they need, or are they encouraged, to participate in training courses?

Our method to get as much general information about the foreign current practice as we can was sending letters into about 80 countries in Africa, Asia, South America and the Pacific Islands. Our target countries were mostly developing ones, usually not far from the Equator, with high insolation level.

There are two main reasons why we targeted developing countries in Africa, South/Central America, and the Middle/Far East. One of them is that it appears as though there is a big market in the so-called "solar belt" (located 30 N to 30 S to the equator), where there are estimated to be nearly 1 million villages not connected to power grids. I.H. Usmaini of the UN estimates that a typical village needs about 9 kW of peak array capacity to meet the minimal energy requirements for 500 people [Matlin, 1986].

The other reason is that countries in the middle latitudes (e.g. not in the solar belt) have a marked disadvantage in the harnessing of direct sunlight since seasonal variability is shown. For example, some places in Africa experience only a 35 percent variation in insolation throughout the year [Hayes, 1978], which is a great advantage in operating PV systems. By contrast, the amount of solar energy reaching more northerly or southerly inhabited geographical locations varies by about a factor of three.

We tried to contact manufacturers, universities and other institutions and organizations participating in any kind of photovoltaic or solar projects or production. We sent 312 letters with a one page questionnaire (See Appendix B) and within about 3 months we got back more than 20 percent of them (62). Nine letters were returned because of wrong addresses (probably because of some relatively old [1981] address data).

A detailed summary of all the answers we have can be found in Appendix C.

2.3. Discussion and Conclusions

The survey replies indicate that there are presently two main approaches to design for export: complete PV stand-alone systems and complete PV manufacturing systems. Only two of the responding companies appear to routinely use foreign parts in stand-alone systems. Thus, between the two extremes of making nothing abroad and making everything except cells abroad, there appears to be little with a mixture of foreign and domestic design, manufacture, installation, and maintenance. Is there an optimal mix for increased PV usage at the lowest cost? The remainder of the study is devoted to the development of a method to answer that question.

The results of the survey show that especially among the developing countries there is an increasing interest in PV stand-alone systems. These are--of course--less complicated than the manufacturing systems and so the receiving countries can provide more parts to be built into these systems and they can finance some small systems more easily than a whole manufacturing system.

Based on the analysis of the market potential in different developing countries (from our surveys and other reports), based on the responses we have obtained from foreign countries, and based on the assessment of human needs, water pumping appears to be the most important application for us to consider for present and near future. The remainder of this study concentrates on water pumping.

3. SELECTION OF COUNTRY AND TYPE OF SYSTEM

For selection of the promising export region, a matrix of relevant parameters associated with each country in the Third World was developed. Parameters such as GNP, degree of electrification, climate, and solar insolation were taken into account. On the basis of several of these parameters, Nigeria was selected as the case study in this investigation. The country selection process is reviewed below.

A typical PV system type was also selected in order to focus the scope of the project and to test the methodology being developed. Water pumping was chosen for several reasons:

1. It was the most frequently mentioned application by manufacturers.
2. The need for clean water on humanitarian grounds is clearly evident. There are "nearly one billion people living in the rural areas of developing countries ... without access to a safe and reliable supply of water" [Meridian, 1987a].
3. There appears to be a huge market potential.
4. There is considerable literature available on the design of water pumping systems [e.g., Sandia Lab, 1987; Matlin et al., 1986; IT Power, 1984].

3.1 Review of Export Potential

3.1.1 Summary

After a review of the population of developing countries, Nigeria and Zimbabwe were chosen for closer scrutiny. The Dominican Republic was also considered.

The two African counties appear to offer a decided contrast. There is little present activity in PV pumping systems in Nigeria and until recently comparatively little development of the industries involved in manufacture of PV system components. A favorable foreign exchange rate and the availability of oil export earnings is said to have encouraged development of assembly industries which used imported components. Changed conditions and devaluation of the Naira have heightened interest in expanding the manufacturing base, however. These factors, plus Nigeria's considerable size (population approximately 105 million) make it an attractive subject.

Zimbabwe is a smaller country (having a population of 8.4 million in 1985) but one which has apparently developed an internal photovoltaic industry. The Dominican Republic is smaller still and is one of several Caribbean Basin countries selected by U.S. Department of Commerce for pumping system demonstration.

One observation drawn from our inquiries about PV systems applications and U.S.-based programs overseas is that, as expected, local circumstances make every situation different. There are no perfectly "typical" overseas markets. Each country exhibits its particular obstacles to expanded imports, and every export-enhancing effort will require tailoring to receiving country circumstances. Proposed methods for optimizing PV system design (such as this study will offer) may or may not accomplish expanded exports by themselves.

Section 3.2 presents the most current official U.S. trade statistics for PV Cells and Panels, by country of destination. These data are not directly comparable with production and export estimates available from other sources (for example [Meridian, 1986]) which use industry surveys and include PV systems as well as cells and panels. Volumes in these compilations are stated in terms of MW capacity rather than value. However these surveys are more comprehensive in, terms of PV products included, they do not offer detail by country of destination and can contribute little to our country-by-country review.

Section 3.3 presents country data from a variety of sources, providing an overview of each. This set of countries includes those usually considered as "developing" countries, plus all countries that have imported U.S. cells or panels in the last five years, plus other countries which have not imported these products but are known to have PV programs or were of interest for other reasons.

3.2 Exports of Photovoltaic Cells and Panels

Table 3.2 contains five year's U.S. exports of photovoltaic materials, by country of destination. These data are presented in descending order of export volume. "Cells" and "Cells Included in Modules or Panels" are combined in the Table though reported separately since January, 1984. These exports are, of course, for power generation, not for consumer items such as watches and calculators.

The major destinations of these materials include Hong Kong and Singapore which presumably incorporate them in systems for reexport (as well as for internal use). Nigeria ranks 12th in terms of imports from the U.S., but it is a distant 12th and its import were concentrated in one year, 1985. Zimbabwe is a minor importer and the Dominican Republic does not appear in these data.

Nigeria's position is somewhat surprising, because, although the evidence points to a large potential market for PV pumping systems, very little could be learned to suggest that such pumps are in use there now to any extent. However, these sales may be for other applications (communications or refrigeration). In any case we would have expected Nigerian imports often to take the form of complete systems with the solar array already incorporated which would not appear in the trade statistics presented. As indicated above, we have no data on PV systems; only on Cells and Panels. Our view is that imports of Cells and Panels can be taken to indicate some familiarity with the technology in the receiving country; more than that can hardly be inferred from this information.

3.3 Aggregate Data Describing Potential Candidates for Study

Table 3.2 contains data describing the developing countries that have contact with U.S. PV technology as evidenced by the import statistics. Sources are given in the footnotes to the table. Much of this information has been compiled in [Meridian, 1986] which provided the brief geographic characterizations. In a number of instances information from Meridian Corp., "International Data Base for the US Renewable Energy Industry", May 1986, was updated from original sources.

Countries should have the following attributes to be considered for detailed investigation:

1. Significant rural population without electrification
2. Internal energy prices close to the world prices
3. Per capita GNP in the mid-range for the continent
4. Satisfactory average insolation measures
5. Absence of political obstacles
6. Commercial contacts with industrialized countries should not be dominated by some other country
7. History of imports of cells and panels from U.S. or experience with PV projects preferred
8. On U.S. DOE list as "target country" preferred

Few countries score uniformly high on all of these items. Nigeria, for example, has kept the internal prices of petroleum fuels well below the world price until very recently; the price of Diesel fuel is still below the world price and still does not reflect its full opportunity cost, the price it would command if sold on the world market. It should be noted that internal fuel prices are at variance with world prices in many countries. In such cases the internal price might not be the appropriate price for a study of social costs and benefits (though private costs may be the relevant costs for predicting how local firms, farmers, or farm cooperatives will make the choice between solar pumping systems and Diesel powered systems).

TABLE 3.1

U.S. EXPORTS OF CELLS AND PANELS BY COUNTRY OF DESTINATION

COUNTRY	TOTAL VALUE , 000 DOLLARS					
	1982	1983	1984	1985	1986	TOTAL
SINGAPORE	98		1399	920	608	3025
SPAIN	350	387	1135	718	108	2698
SAUDI ARABIA	73	489	945	780	12	2299
MEXICO	58	17	292	230	1014	1611
HONG KONG		318	312	213	691	1534
REP SAF	173			250	908	1331
CHINA M				1185	96	1281
COLOMBIA		31	219	70	702	1022
MOROCCO	16		200	56	676	948
EGYPT	63		80	182	519	844
INDONESIA	697					697
NIGERIA				684		684
KOREA			203	227	251	681
BRAZIL	462	111				573
MALAYSIA	182		53	49	261	545
TUNISIA	520					520
ARAB EM		420			59	479
TANZANIA			438			438
ISRAEL				137	210	347
YEMEN				104	222	326
GUYANA			320			320
ALGERIA			46	72	201	319
CHINA T			100	150	32	282
KENYA			37		218	255
CHILE		16		28	202	246
OMAN	221			22		243
NAMIBIA			41	140		181
SOMALIA					178	178
PHILIPPINES			165			165
ZIMBABWE		10	74	74		158
ZAMBIA	10			146		156
SALVADOR			147			147
ARGENTINA	21			55	68	144
YUGOSLAVIA				133		133
PACIFIC IS		125				125
NETH.ANTILLE			120			120
PERU					114	114
PORTUGAL					110	110
TURK IS.		108				108
PARAGUAY					91	91
MALI			22	68		90
VENEZUELA				18	63	81
ETHIOPIA				74		74
BOLIVIA			67			67
THAILAND				37	29	66
ECUADOR			33		28	61
BANGLADESH					58	58
INDIA			13	42		55
HAITI		6	54			60
BENIN					41	41
BARBADOS			22			22
NEPAL					19	19
BAHRAIN	16					16
IRELAND						0
TOTAL	2960	2038	6537	6864	7789	26188

Table 3.1 - Sources

U.S. Exports - Commodity by Country, Schedule E, FT 410, U.S. Dept. of Commerce, January 1982 - January 1987.

a. 7763050 - Cells inc. Modules and Panels (before January 1984)
b. 7763057 - Solar Cells
c. 7763054 - Cells except those inc. Modules and Panels

TABLE 3.2

SUMMARY INFORMATION FOR CANDIDATE COUNTRIES

COUNTRY	TYPE OF CLIMATE	INSOLATION	POPULAT (000)	% RURAL	%RURAL ELECTR.	% RURAL WATER	PER CAP GNP US($000,000)	VALUE ADDED AS % GNP MAN.	MIN.	ENERGY	%EXPORTS /IMPORTS	%EXPORTS /GDP	BAL.TRADE mill.US $	XT.DEBT per capita	DEBT SERV % GNP	ELECTR. CAPITA	ELEC.PRIC cents/kwh	DIES.FUEL US$/GAL.
ALGERIA	mtn,plains,desert	1907-2328	21865	55	33		2530				108		826	710	8.1	33.5	5.07	
ARGENTINA	mtn,plains,coast	1584-1975	30531	17	05	17	2130				174		3332	1586	6.1	1401.5	5.50	0.58
BENIN	plains,coast	990-1115	4043	85		15	270							191	2.2	39.8	9.40	0.44
BOLIVIA	mtns,basin	2005-2010	6383	55	09		470	.104			153.7	12.4	286	622	6.5	289.7	3.73	1.47
BOTSWANA	arid,plateau	2123	1070	80			840	.012	.243	.023					6.9	554	4.40	1.01
BRAZIL	plains,coast	1483-2058	135539	33	03	53	1640	.138		.001	149.6	12	8326	787	3.7	1196.5	7.79	1.34
CHILE	mtns,coastal	1770-2052	11990	20	41	18	1440	.219			139.3	19.4	1082	1686	8.7	1032.5	3.60	1.48
CHINA	coast,mtn,desert	1554-2325	1041094				310				103.9	9.4	827			325	3.3	0.71
COLOMBIA	coast,mtns	1278-2011	28418	35	26		1320	.020			62		-1886	494	4.3	836.8	3.60	0.95
DOMINICAN REP.	lowlands,mtns	2305-2308	6261	47		32	810				50.7		-631	526	3.1	622.8	13.01	0.66
ECUADOR	mtns,lowlands	1281-1784	9367	54	13	21	1160	.115	.119		150.4	17.2	738	985	8	379.1		0.32
EGYPT	desert,nile,sea	1938-2117	47108	55	23		680	.008	.028		31.3		-7059	516	7.8	399.9		0.12
EL SALVADOR	mountains	2250	5564	58		42	710	.126			82.4	19	-157	312	5.3	312.1		1.7
ETHIOPIA	coastal,plateau	2052-2185	42271	85	0		110	.110			46.1	12	-472	44.0	2.2	20.9	7.00	1.44
GUATEMALA	mtns,lowlands	2065-2145	7966	60	07	26	1240				102.1	12.6	24	325	2.3	211.7	13.40	1.2
GUYANA	lowlands,mtns	1569-1574	806	77	03	60	570						-7			555	25.05	0.25
HONDURAS	mtns,lowlands	1753-1760	4366	63		55	730				80.2	22.4	-163	1600	5.4	275.9	7.35	1.2
KENYA	arid,highlnd,coast	1967-2732	20375	85	06	15	290	.019	.035		72		-381	203	6.9	110.3		1.61
MALI	desert,valley	2140-2500	7511	81			140				48.5		-177	195	3.5	15.5		2.04
MAURITANIA	desert,plains	2085-2173	1693	74		85	410				134.5		78	872	12	97.3		2.16
MEXICO	mtn,coast,plateau	2001-2486	78820	32	43	40	2080	.023	.0006		256.2		12812	1230	6.5	1102.6	2.77	0.25
MOROCCO	plns,coast,mtns	2318-2414	21924	58	06		610				57.3		-1537		9.3	337		1.36
NAMIBIA			1127															
NETH. ANTILLES	island	2069	264				6110				97.4		-117					
NIGERIA	plains,coastal	1497-2121	99669	86		30	760	.073			84.2	32.2	-2123	184	5.3	82.6		0.58
PARAGUAY	low,plateau	1912-1947	3388	60		10	940				56	4.4	-223	525	5.6	292		1.37
PERU	coast,plains,	1278-2453	18653	34	10	18	960	.0002		.002	141	17.2	880	733	1.9	595.4		0.79
SOMALIA	highlands,coastal	2226-2235	5384	68		21	270	.024		.003			-215	276	2.3	16.6		
TANZANIA	plateau,coast	2182-2306	2242	87			270							1600	1	42.8	7.70	1.83
THAILAND	penin.,plateau,mtn	1814-2021	50950			70	830				61	15.5	-4004	343	4.1	364.7	7.9	1.15
TUNISIA	coast,desert	1991-2011	7143	46	31		1220	.121	.109	.020	60.1		-1245	734	8.6	478.2	6.20	0.8
VENEZUELA	mtn,lowlands	1715-2359	17323	16		65	3110	.217			225	22.6	8334	1851	4.6			0.07
ZAMBIA	plains	2250	6640	55		33	400				120.5	24.9	141	675	4	1750.9		2.64
ZIMBABWE	highlands	2221	8406	76	0		650	.256	.068	.023	107.3		77	254	6.7	1015.3		2.01

Table 3.2 - Sources

Meridian Corporation, International Data Base for the U.S. Renewable Energy Industry, May 1986 (Prepared under U.S. Dept. of Energy Contract No. DE-AC01-86CE30844)

International Monetary Fund, International Financial Statistics, August 1987.
United Nations, U.N. Statistical Yearbook, 1984.

World Bank, The World Bank Atlas, 1987 (Washington, DC)

World Bank, The World Development Report, 1987 (Oxford, University Press)

4. COST AND AVAILABILITY OF INPUTS

The hypothesis of this study is that increasing the share of value-added taking place within the receiving country will make it significantly easier for that country to import solar-powered pumping systems (or photovoltaic systems of any sort, for that matter), by lowering system cost and foreign exchange requirements. Therefore, we are interested in the state of industrial development and the availability and cost of particular products and skills in the receiving country, in this case, Nigeria.

The information obtained from Nigerian sources provide an indication of the system cost savings that might be obtained with maximum use of present-day Nigerian construction, manufacturing, and servicing capabilities. However, though the data are useful they are limited; the cost results reported here should therefore be used with caution.

For example, if the Nigerian government were to choose to use solar pumps as a vehicle for further development of its industrial and technological capabilities, best estimates of costs and capabilities would likely change. This scenario might usefully be investigated with the methods developed in this study, which emphasize flexibility. Improved estimates or alternate scenarios can easily be incorporated and evaluated.

4.1 The Industrial Base and the Availability of Solar System Inputs

Expansion of the country's industrial base has been a major economic development objective of the Nigerian government. The Structural Adjustment Program put into effect by the present Government assigns the top priority to rural and agricultural development [US Dept. of Comm., 1987a]. Clearly, the the connection between the industrial base and the agricultural and rural sector presents opportunities and imposes choices on Nigerian policy makers.

Industrial growth had tended to center in assembly industries, of which the automobile is the principal example, as part of a pattern of import orientation. Nigeria was able to import components for local assembly, rather than develop the earlier stages of manufacture. The recent rapid decline of the Naira against other currencies associated with the decline in oil prices has made assembly from imported components economically less attractive, and production in these segments have declined sharply.

This general description is borne out by various economic indicators: the Index of Manufacturing Production for Vehicle Assembly as reported by the Central Bank of Nigeria fell from a high of 5463.3 in 1982 (1972 = 100) to 689.3 in 1984 and 723.8 in 1985 [Central Bank of Nigeria, 1985]; a similar pattern is reported for Synthetic Fibers, Cotton Textiles, and a variety of other products. The overall Index peaked at 432.7 in 1982, falling to 280.8 in 1984 and returning to 334.8 in 1985. The Bank observes that the recovery in these items between 1984 and 1985 followed from the imposition of stringent foreign exchange controls that reduced competition from imported consumer goods.

Reported output for major industry categories suggests that input materials and services for small buildings, support structures and other construction required for solar pump systems are locally available.. Nigeria has a cement industry of modest size (3,009 metric tons in 1982 [Central Bank of Nigeria, 1985], but much reduced in 1985). Wood and wood products are produced locally (and import of finished wood is prohibited).

A one-million ton integrated iron and steel mill was placed in operation at Aladja, Bendel in 1982. The complex will roll some of its steel output, and will support rolling mills at Oshogbo, Jos and Katsina [Central Bank of Nigeria, 1985]. "Roofing sheets" are the only steel product for which production is specifically reported in the official statistics, but the description of the facilities suggests that a range of rolled products are being produced or could be produced. It should be feasible to form the sorts of light-weight structural steel parts used in array assemblies or supports. Light-weight structural steel (3/16" x 1 1/2" x 1 1/2" angles and 3/16 " flats) appear to be locally available [Nwokogba, 1988].

Machinery or equipment is a major import category for Nigeria and its availability from local sources must be viewed with caution (Machinery and Transportation Equipment were estimated to be 43% of all imports by Nigeria in 1985 [Central Bank of Nigeria, 1985]). Battery chargers for radio and television applications are manufactured locally; products such as pumps and motors are likely to be assembled from imported components and to be at a large cost disadvantage over imported pumps [Nwokogba, 1988]. Those made entirely locally may not be of the precision manufacture and efficiency best for solar pump applications. However, the Federal Ministry of Industries reports that pumps are available from local sources though it is not clear whether entire pumps are being produced as opposed to assembly from imported components. As for particular capabilities that might support the manufacture of system components, there are reported to be iron and steel foundries in operation; these might produce pump casings or motor parts.

Flat glass is made in Nigeria, though the availability of tempered, low-iron glass was not established. (Low-iron glass has a higher solar transmittance than ordinary window glass). Insulated copper wire is produced, from imported larger-sized wire [Ballard, 1987].

It might also be noted that Nigeria has had in force a policy of encouraging the development of particular industries that are considered important to growth and development. These "pioneer industries" include cement, glass, machinery that uses locally made components, iron and steel, and nonferrous metals and alloys.

The outlook for support in the services area is encouraging. The University of Lagos, in responding to our earlier international survey of activity in photovoltaics reported that local sources could provide installation and maintenance services for photovoltaic modules, wiring, voltage regulators, and loads including water pumps. This should not be particularly surprising since Nigeria presumably has some photovotaic equipment now in operation: they imported cells and modules from the U.S. in the recent past (see Section 3), suggesting existence of a capability for assembly of entire systems as well as a need to perform installation and maintenance. Photovoltaic systems are undoubtedly operating in Nigeria today, but no inventory of systems or applications is available.

We are also advised that machinery repair services of several types are available, some operated by multinational trading companies to support their products. Repair and maintenance of emergency power systems seems to be generally available in the cities. Both these circumstances suggest that maintenance service organizations will come into being in response to a sustained demand.

Well-drilling, though not part of the solar pumping system per se, is obviously an important service from the standpoint of the development of water supply. Nigeria is involved in at least two ambitious well-drilling programs, one financed by the Nigerian government and one sponsored by the World Bank. Well-drilling services are provided by local firms.

These observations are supported by the two responses to our questionnaire relating to prices and availability of solar parts and materials, presented below in Table 4-1, Cost and Availability of Selected Goods and Materials, and Table 4-2, Nigerian Labor Rates.

Table 4-1

Cost and Availability of Selected Goods and Materials
(in Naira, 1988)

	A	B
Structural Steel 1 1/2" Angle (30' Length)	40.00	27.50
Structural Steel 1 1/2"x 3/16" Flat (30' L.)	15.00	50.00 (Per Plate)
Wood -- 2"x4" Dimension Lumber (Hard Wood)	15.00	15.00
Fencing (2 M. High, per M.):		
Wood	50.00	45.00
Steel	180.00	200.00
Concrete Block	100.00	150.00
Glass -- Flat (Low Iron) 36" x 24"	45.00	45.00
Copper Wire (Insulated -- per 100 M.)		
1.5 mm2 Single Core PVC	73.00	-
2.5 " " " "	109.00	-
4.0 " " " "	176.00	-
6.0 " " " "	260.00	-
10.0 " " " "	422.00	-
PCV Pipe (per meter)		
1" Equiv.	-	16.41
11/4"	2.50	-
11/2"	3.17	-
2"	4.00	-
Galvanized Pipe -- 1" (per meter)	9.00	19.70
Electric Motor (DC, Perm. Magnet, 120 or 12 V., 1/2 HP)	800.00	400.00
Voltage Regulator (12, 24 or 48 V)	2,500.00	380.00
Batteries (Deep Discharge)	2,000.00	300.00 - 1,700.00
Equipment Boxes -- 2'x2'x1 '(Steel)	1.50	500.00 (Import)

Water Pumps			
Volumetric (Jack)			
0.5 HP	650.00 (Local)	-	
0.75 HP	950.00 "	-	
1.0 HP	1,500.00 "	-	
10.0 Cu.M./Hour (With Accessories)	-	14,000.00 (Domestic)	
DC Vertical Turbine (30 Cu.M./Day)	-	25,000.00 (Domestic)	

Notes:
A: Federal Ministry of Industries, Garki - Abuja, Nigeria
B: Paho Water and Civil Engineering Co., Lagos, Nigeria
Exchange Rate -- $0.2415/N- (December, 1987, International Financial Statistics, International Monetary Fund)

Table 4-2

Nigerian Labor Rates
(Naira per Year)

	A	B	Fringe Benefits (Source B Only)
Laborer	2,600	2,400	30%
Carpenter	3,900	3,600	20
Electrician	3,900	5,400	27
Elec. Maint. Spec.	8,400	6,400	26
Engineer	14,400	9,000	20
Heavy Eq. Oper.	3,900	4,800	30
Machinist	3,900	3,600	20
Mech. Maint. Spec.	8,400	6,400	26
Foreman	4,800	7,200	23

Notes:
A: Federal Ministry of Industries, Garki - Abuja, Nigeria
B: Paho Water and Civil Engineering Co., Lagos, Nigeria
Daily rates converted to annual at assumed 260 days/year.
Exchange Rate: $0.2415/N- (December, 1987, International Financial Statistics, International Monetary Fund)

In summation, the following conclusions about the availability of materials, components and services are offered:

- The materials for array frames, for support structures and for buildings, storage tanks, or fencing are locally available.

- Construction services, system installation services, and system maintenance services are locally available, or at least there is a local base on which to build.

- The capability for cell and module manufacture would have to be created; there apparently is no requirement for these parts in any volume now, so we would not expect to find a production capability in place.

- The local availability of other component parts is problematical at this time. Minor parts and materials for wiring and assembly are undoubtedly available. Tempered glass in sheet form would seem to be within Nigeria's capabilities; it is not known if low-iron glass can be produced. Pumps and motors are apparently available but are relatively expensive. Locally manufactured pumps may become become available as Nigeria's water development projects grow.

4.2 Input Prices in Nigeria

As noted above, the plan of this study envisioned the use of current labor rates and component prices from Nigeria for those solar pump system components and related services that are available there or could feasibly be produced there. Current data were obtained from two sources, one governmental and one from the private sector. These are limited, clearly, but the sources are usually consistent with one another and with other information.

4.2.1 Materials and Components Costs

Table 4-1 will not be reviewed in detail, but it will be noted that there are several cases where the prices reported vary so considerably for the two respondents or from U.S. prices that we must assume they refer to different products or specifications. This reflects a problem in seeking such information by questionnaire: we did not wish to confine respondents to particular technical specifications for pump parts in case the locally available part might be a close substitute with different size, capacity or other specification. Our solution to this problem was to ask respondents to provide price and availability information about a part that performs the desired function and to provide the technical description for the part they used in the response. This worked well in some situations but not in all.

4.2.1 Wage Rates

Current wage rates for Nigeria are reported in Table 4-2. As a check on the data of Table 4-2, we compared the daily earnings series for "Wages in Manufacturing" and "Wages in Construction" published in the 1986 Year Book of the International Labor Organization (Table 17 and 19 in that report, respectively) [Int. Labor Org., 1986].

The most recent year for which the I.L.O. earnings series is available for Nigeria is 1980 when wages were reported to be N-4.30 per day in manufacturing and N-4.37 in construction. This source also provides a cost-of-living index for Nigeria through 1986 which increased by 263.3 percent during that interval (Table 23 [Int. Labor Org., 1986]). Wages rose somewhat more rapidly than the cost of living during the latter 1970's, so we assume that they would continue to increase by at least the amount of the index by 1986. To convert 1986 wages to 1987 prices, a recent U.S. estimate of the GNP deflator for Nigeria was employed; it puts the likely price increase for 1987 at approximately 20% [US Dept. of Comm., 1987a].

Upon conversion to annual rates at an assumed 260 days per year, the I.L.O. rates become the following in 1987 N-:

Construction -- N-2,584.4/Year
Manufacturing -- N-3,350.8/Year

Fringe Benefits are presumably not included in the I.L.O. data. Both the adjusted I.L.O. figures and the current wage rates reported dats are distinctly lower than the average U.S. wages reported for 1986 ($102.76 and $131.56 per day for manufacturing and constructions respectively (including an allowance of 30% for fringe benefits) [U.S. Dept. of Comm., 1987b]. $102.76 per day is approximately equivalent to N-110,600 per year.

The current Nigerian wage data presented in Table 4-2 appear to be consistent with the adjusted I.L.O. wage rates (which can at best be very approximate) and they are certainly more recent; these figures are used in the design cost estimates in the following section.

4.2.2 Alternate Procedure for Local Cost

In several instances where we did not have a local price, or an itemization of physical inputs on which to base a cost estimate, we employed a simple estimating procedure to derive Nigerian production costs from U.S. costs. The exact procedure used to form these estimates varied somewhat from case to case, but the general approach is as follows:

1. Estimate the percent of total value of the labor

component of each product or service as produced in the U.S. or provided by a U.S. vendor from available, industry-wide sources.

2. Estimate the ratio of Nigerian labor costs to U.S. labor costs.

3. On the assumption that the cost of the non-labor share of the piece, subsystem or service is approximately the same in both countries, estimate the Nigerian price by reducing the labor component of the U.S. price in accordance with the relative average labor costs of the two countries.

This procedure is obviously very approximate: by adjusting only the labor share of the articles that are direct inputs to pumping systems, we neglect the labor component of the inputs to those articles if they were manufactured in Nigeria; for those inputs that are imported we in effect neglect transportation and import duties in assuming their Nigerian cost is the same as their U.S. cost; we assume Nigerian industry and labor is as efficient as U.S. industry regardless of the differing scale, state of training, etc., and in effect assume that U.S. technology has been transferred to the receiving country; we neglect any effect of the substitution of labor for capital in Nigeria, relative to the U.S.

However, by accounting for the first-tier labor cost differential, however roughly, we undoubtedly address the most important cost effect. The estimates were derived as follows.

Nigerian Labor Costs: For construction labor we assume a workforce composition of 50% laborer, 20% carpenter, 10% electrician, 10% heavy equipment operator and 10% foreman; for manufacturing we assume 50% laborer, 30% machinist, 10% maintenance specialist, and 10% foreman. Using the rates and fringe benefits of Table 4-2 and averaging the data for "A" and "B", we obtain the following:

Construction -- N-4,419.05
Manufacturing -- N-3,981.2

Nigerian/U.S. Wage Cost Ratios: The ratios of labor cost for the labor component of manufacturing and construction were derived by converting Naira to Dollars at the 1987 exchange rate of .2415 $/N-, expressing both wage rates in $/day and dividing the Nigerian rates by the U.S. rates.

Construction --
Wage Cost Ratio = (N-17.00) * .2415 $/N-) / $131.56 = .031
Manufacturing --
Wage Cost Ratio = (N-15.31) * .2415 $/N-) / $102.76 = .036

Nigerian-U.S. Product Cost Ratios: These cost ratios are used in conjunction with U.S. price information and estimates to derive component and construction cost estimates for Nigeria where local prices or input information were not available. Table 4-3 summarizes the procedure used.

TABLE 4-3

Nigerian Production Cost as a Percent of U.S. Cost: Selected Industries

Industry	Percent Labor (1)	Wage Cost Ratio	Nig'n Cost/ U.S. Cost (%)
New Construction	30.6	.031	70.3
Glass and Glass Products	38.7	.036	62.7
Stone and Clay Products	27.4	"	73.6
Heating, Plumbing, Structural Steel Products	27.7	"	73.3
Other Fab. Metal Products	30.4	"	70.7
Elec. Industrial Equipment and Apparatus	36.7	"	64.6
Rubber and Plastics Products	27.3	"	73.7
General Elec. Machinery and Equipment	33.6	"	67.6
Electronic Components and Accessories (includes semi-conductors)	36.9	"	64.4

(1) Labor as a percent of total value of sales, extracted from the "U.S. Input-Output Model, Commodity-by-Industry Direct Requirements" [US Dept. of Comm., 1983].

4.3 Review: Sources and Assumptions for Local System Procurement Cost Estimates

In as many situations as possible, local wage rates and prices were applied to the physical inputs to a solar system component. In the case of cell and module production, for example, the local wage rates presented in Table 4-2 were applied directly to the manning table recommended by the manufacturer of the manufacturing equipment.

Manufacturing equipment for cells and modules is assumed to be available from the U.S. only; there is no locally produced counterpart. A number of further assumptions were employed to obtain cell and array production costs, for which a production facility with related overheads would be required. In brief, the cost of a 10,000 Sq. Foot building was included, and an allowance for materials, utilities, and administrative costs was included at 20% of direct costs. Labor costs were obtained by applying local wage rates as reported above to the manufacturer's recommended manning level. The services of a Nigerian engineer or technician were also included (though this is not part of the manufacturer's recommended staff); this individual would divide his time between cell and module production. No consideration was given to training costs or learning curve effects. It is assumed that all of the output of this plant will be sold, in a solar pump program or in some other application.

For U.S. supplied material, an import duty of 10% was assumed after consultation with the Office of International Trade of the U.S. Department of Commerce. An exception was made for manufacturing equipment necessary for production of cells and modules in Nigeria. No import duty charges were included for these items on the reasoning that their import would likely be officially encouraged, not taxed.

Shipping costs used are for sea freight (20 foot containers from Boston or New York), obtained from freight forwarders. Sea time is about one month, with sailings at three-week intervals.

A seyen year useful life was assumed for building and equipment.

The Maximum Power Tracker, which adjusts the load to the power being delivered by the solar array for maximum efficiency was assumed to be U.S. produced only because of its complexity.

For purpose of selecting the most economical design, cost comparisons are made on the equipment as delivered at Lagos. For the analysis of demand, complete, installed systems costs are needed. An allowance is made for delivery to assumed sites in Sokoto, and well costs equivalent to $300 per meter were included (this figure is similar to that used in other studies, confirmed by persons familiar with well-drilling in Nigeria [Nwokogba, 1988]). Well depths in Sokoto were supplied by Paho.

For the pump and motor set, current prices as reported from Nigeria were used for the local manufacture option. These are quite high, and virtually preclude use of local sources for this item.

A complete table of system component cost estimates and further particulars of the derivation of local estimates are presented in Section 6.

4.4 Summary

The principal procedures and assumptions may be summarized as follows:

1) The high technology required for local manufacture--production of cells and modules--is assumed to be imported by Nigeria in the form of the manufacturing equipment.

2) One item was not considered for local manufacture because of its complexity (the Maximum Power Tracker).

3) Locally produced pump sets and copper wire were reported as being expensive relative to U.S. prices.

5) For other inputs it is assumed that local supply is available and that prices will reflect the lower wage rates in Nigeria, as outlined in Sections 4.2 and 4.3, and Table 4-3. This supposes that the pumping program will be large enough to allow efficient production supply channels to set up.

6) When the U.S. and Nigerian prices were compared for other inputs (as was possible in a few cases) they appeared to be comparable and in some cases lower (presumably due to lower labor costs). Lumber--finished wood--appears to be priced higher in Nigeria, but import of this product is presently banned.

5. WATER AVAILABILITY AND DEMAND

5.1 Introduction

This part of the report studies the expected demand for water pumps in Nigeria, specially in the more arid sections of the northern part of the country. The study accepts the findings of the Meridian Report(1) that established the range within which PV water pumps are more cost-efficient than hand-pumps and diesel pumps. Thus the study does not dwell on the merits of PV water pumps versus hand or diesel pumps.

In the first part of this section, the report studies the feasibility of using PV water pumps in Nigeria. It looks first to the availability of water resources both in terms of surface and ground supplies, as well as to the depth of water tables. Once water availability has been established, the report examines the present demand of water and the programs that exist to fill that demand. In the last section the report addresses the question of effective demand, i.e. whether the income of the agricultural sector is high enough to finance photovoltaic water pumps.

5.2 Water Resource Availability

Nigeria represents conditions where the use of photovoltaic pumps for village water supply and for irrigation of small size agricultural plots would likely bring large benefits to the farm sector of the nation as well as to the process of economic development in which the nation has engaged so seriously since the time of independence.

Nigeria lies in the central western part of Africa. The southern part of the nation shares a high humidity weather pattern, where the rainy season is long and the vegetation is typically tropical. The northern part of the nation on the other hand resembles more the weather characteristics of the Sub-Sahara Desert location with short rainy seasons and long dry seasons. Measurements on stations of six of the nineteen states in Nigeria had from 1980 through 1984 four months or more with zero precipitation, which is a record that approximates the long-run average for these states (Table 5-1). From November to March

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(1) See the executive summary of Meridian Corporation, "A Comparative Assessment of Photovoltaics, Handpumps and Diesels for Rural Water Supply". Alexandria: Meridian Corporation, 1987.

stations on the states of Sokoto, Kano, Borno (Maidiguri), Gongola (Yola), Bauchi and Niger (Minna) recorded no rain at all. Among them, Kano and Yola experienced no precipitation either during the month of March. Another two stations in the states of Kaduna and Plateau (Jos) had no rain for three consecutive months of the year.

This type of record might raise questions about the availability of water resources or the economic feasibility of developing whatever meager resources the nation, and specially the northern part of the nation, might have.

Nevertheless Nigeria has a relatively ample base of water that can be utilized in different forms. The problem seems to be not one of availability but of utilizing resources in an efficient manner. As J. O. Ayoade writes:

> "Nigeria is reasonably endowed with water resources, both surface and underground. The main problem is that of development and management rather than that of water availability."(2)

The nation is covered by a wide net of rivers, dominated by the major river, the Niger, and its largest tributary, the Benue. Only the northeast corner does not exhibit this river coverage. But the proximity to Lake Chad makes even this corner not completely deprived of surface water resources. The potential amount of water surface resources in Nigeria have been estimated at about 1.262 trillion liters per day(3), while the total demand based on a per capita consumption of 115 litters per day, assuming a population of 99 million, would amount to 11,385 million liters per day. That is, the potential of surface water resources, after discounting for losses due to evapotranspiration and discharges into the ocean, is the equivalent of 110 times the upper limit of water consumption (Table 5-2).

The potential volume of ground water is difficult to estimate but there appears to be common agreement about its considerable abundance. Most of the rivers of the country, except for the short costal rivers of the south sections, are fed during the non-rainy season from ground water resources, thus indicating the ability of the ground to retain water from rain sources. Ground water reserves have been estimated to be thirty times the volume of surface water resources(4) . Ground water resources are the least developed in Nigeria, but present nevertheless the best potential for making it the primary source of water needs.

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(2) See Ayoade, J.O.. 1981. "On Water Availability and Demand in Nigeria". Water Supply & Management, Vol. 5 No. 4/5 p.369.
(3) Ayoade, J.O., op. cit., p.369.
(4) Ojiako, G.U., in 1985. "Nigerian Water Resources and Their Management". Water International, 10 (1985), p.67.

5.3 Water Tables

If ground water is as abundant as these estimates indicate, the next question to be raised then would be related to the possibility of extracting it from the soil, and thus firstly to the depth of the water tables. Studies have shown that the depth of ground water is a function of the geological formation of the soil, the distance from a river and the time of the year.

Nigeria is composed primarily of two different types of soil rock formations, the Sedimentary Strata and the Basement Complex. The first one presents ideal conditions for ground water resources development since it has abundant surface and ground water resources. The Basement Complex serves as the base of riverheads and reservoirs of ground water. It is not a geological formation that contains ground water as efficiently as the previous one. Nevertheless studies done on the water tables in areas of the Basement Complex show that the depth of the table varies inversely with the distance from a river and with the proximity of the rainy season(5). Estimates from the correlation between depth of the water table and distance from river for the end of the dry season would give the following figures(6) :

Distance From River (in km.)	Water Table Depth (in meters)
20	6.9
40	11.8
100	26.2

5.4 Water Demand

5.4.1 Present Conditions

(5) See Omorinbola, E.O., 1982. "Predicting Depth to the Water Table in Deeply Weathered River Catchments in Nigeria". Journal of the Institution of Water Engineers and Scientists. Vol 36, No. 3, May 1982.

(6) The estimates are from his last equation, where distance from the river and season of the year are incorporated. The coefficients for the driest month of the year is selected to derive the estimates.

Nigeria had relied since pre-colonial periods on traditional methods of water supply. Piped water was introduced with the development of modern cities, but the rest of the nation, especially the agricultural sector, obtained its water from collected rain water and hand dug wells. In the more arid regions of the northern states, these water supplies dwindled during the dry season (November-March), when the wells and small rivers dried. The traditional sector had taken the lack of water during some part of the year as a factor that could not be changed, and adapted its agricultural practices to these conditions. The farming sectors developed indigenous technologies, such as mixed simultaneous planting, that adapted the cultivation of crops to arid, flood and other conditions of the particular region. The lack of water resources forced cattle farmers in some of the north-western regions to migrate annually in search of water supplies.

Traditional irrigation farming was limited to the seasonally inundated depressions and seasonally flooded riverine land (the fadama). It is estimated that this type of traditional irrigation covered about 800,000 hectares by the 1970's. The World Health Organization estimated that by this period only .009 percent of the total north eastern area and .0014 percent of the north western states had any type of irrigation. If we look at water for home consumption, the same organization estimated that at this time only 8% of the rural population had "reasonable" access to water supply(7) .

5.4.2 Recent Developments

With independence and later on with the revenues from the oil boom the government embarked in plans to develop water resources in the nation. In 1975 the government created the Federal Ministry of Water Resources and in 1976 eleven River Basin Development Authorities to manage the development of water resources, but up to the present time these efforts have been mostly restricted to large scale irrigation projects. Nigeria has constructed three large reservoirs and dams with the purpose of generating electric power and irrigating lower terrain. The projected irrigation coverage under these plans is given below(8):

(7) in Leeden, Frits van der. "Water Resources of the World". Water Information Center, Inc., 1981, p.485 and p. 515.
(8) in Nelson, Harold D.. 1982. Nigeria: A Country Study, United States Government: Department of the Army. p.155.

PROJECT	PROJECTED IRRIGATION (in Hectares)
Small Plants	9,000
South Chad	22,000
Bakalori	24,000
Kano River	24,000
TOTAL	79,000

By 1991 the original estimates envisaged a total of 274,000 hectares of irrigated area at a cost of 2.2 billion Naira(9). Questions have been raised about the cost/benefit ratio of these projects, and progress has slowed down since 1981. The projects have, according to the critics, displaced farmers and farming methods that were highly productive in these areas. Aside from these possible shortcomings, these projects represent a very small percentage of the land that needs irrigation. The Food and Agricultural Organization of the United Nations estimates that total cultivable area of Nigeria to be about 91 million hectares, of which at the present only 23.8 million are actually cultivated. These projects represent merely .33% of the actually cultivated area and .08% of total cultivable area. The implicit demand for irrigation is large. One of the reasons, according to the same source, of why only 26% of the cultivable land is actually utilized is the lack of irrigation(10).

The supply of water for domestic use in Nigeria has developed unevenly. A large percentage of the population does not have sufficient access to reliable and sanitary sources of water supply. The supply of pipe-borne water is limited by and large to large cities. By 1976 there were 261 towns with modern water supplies, serving a population of 17.967 million people(11) . The average per capita use of water for these towns is of 58.29 liters per day per person(12). This figure may be inflated since per capita use was derived by dividing the total possible supply of water sources by the number of people in that particular locality.

The number of people served by modern facilities represented at this time 23% of the population. The remaining 77% of the

(9) in Ojiako, G.U., op. cit., p.71
(10) referred to in H. Nelson, op. cit., p. 186.
(11) J.O. Ayoade, op. cit., p.365.
(12) The World Health Organization gives for Africa a daily consumption of 45 liters, op.cit., p.85.

population had to rely on traditional methods of water supply, such as hand dug wells, collection of rain water in containers, spring and surface water. Many of these facilities do not meet basic sanitary requirements, which explains the high incidence in the rural sector of guinea worm and dysentery.

5.4.3 Government and International Agencies Role

Since 1976 the methods and status of water supply has not changed substantially(13) . The financing of water supply infrastructure has traditionally been considered to be a role of the government sector. Actually the supply of water to rural and urban communities is by constitution the responsibility of State Governments. The government, although increasing the absolute amount of expenditures for water projects, has been devoting a smaller percentage of its capital expenditures to domestic water development. As a percentage of total capital expenditures, investment has gradually declined from 7.7% for the 1955-1960 period to 2.8% for 1975-1980. A large portion of the rural northern sector has not benefited to a great extent from government programs. The government in the northern states has emphasized work to improve conditions of water supply in a few widely separated large cities, without expanding into the villages in between. In the southern part of the country on the other hand, cities and its surrounding villages have been taken as targets of water improvement projects.

Besides government programs, other international agencies are engaged in projects to improve domestic water supply. The World Bank has installed 1,400 boreholes in the state of Sokoto and is the process of extending the program to another 1,000 boreholes in the same area(14). The same source of information indicated that the World Bank plans to expand rural water supply points at a rate of 250 per year, with no information provided about the site of such projects. The World Bank too is involved in what is referred as the Integrated Agricultural Project. By 1985 it was estimated that 3,831,000 families would benefit from these projects(15) . The money spent on irrigation is small, with the greatest part of the budget devoted to the development of high yield seeds, chemical inputs, agro-service centers and others. In spite of all these efforts both by domestic government agencies and international organizations, there is ample room for

(13) J.O. Ayoade, op. cit., p.369.
(14) from communication with David Howarth of the World Bank.
(15) M. Watts and P. Lubeck, 1983. "The Popular Classes and the Oil Boom: A Political Economy of Rural and Urban Poverty", in William Zartman, The Political Economy of Nigeria. New York: Praeger Publishers.

improvement in the rural sector and specially in the upper half of the nation.

5.4.4 Ground Versus Surface Water Demand

As it was mentioned above, the solution to the shortage of water supplies, specially in the northern states, ought to be sought more in terms of ground water than surface water development. Several reasons are presented in the literature. The first is due to the high level of evapotranspiration. Annual mean rainfall decreases almost directly from south to north. About three quarters of the nation has 1250 mm or less of annual mean rainfall. In the upper northeast corner it declines to 750 mm or less.

As the rainy season becomes shorter, the hours of sunshine increase and with them the rate of evaporation. In the Sudano-Sahelian zone of Nigeria average annual sunshine is over 2500 hours (Table 5-3). Along with clear skies, the temperature does not exhibit great variation. The maximum temperatures range between 31 and 35 ^{o}C with the minimum ranging between 17 and 20 ^{o}C for most part of the year(16). A study of seven river basins in this zone (Sokoto,Rima, Chalawa, Kano, Hadejia, Jama'are and Yobe) shows that in normal years the volume of actual evapotranspiration constitutes 66% of the mean annual rainfall. This combination of high degree of insolation, low annual rainfall and high degree of evapotranspiration produces several consequences not conducive to surface water development projects.

Firstly, the discharge of rivers on which reservoirs and other exposed water storage depend upon suffers from a high degree of evapotranspiration and tend to be small. In the above mentioned river basins the discharge rate for six of them ranged from 3.3% to 12.6% of estimated water input. The other two had a slightly higher discharge rate of 17 and 26 percent.

Secondly, the loss of water from reservoirs and lakes due solely to evapotranspiration has been estimated to be 284.5% of that which would exist on ground under seasonal conditions of water availability. Lake Chad, for example, will cover during its high months of December and January about 26,000 square kilometers, but its surface will be reduced to less than half by the end of the dry season. An aggravating factor is added by the fact that during droughts, when the feeding sources have dried up,

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(16) see E.A. Olofin. 1985. "Climatic Constrains to Water Resource Development in the Sudano-Sahelian Zone of Nigeria". Water International, 10 (1985)

evapotranspiration will still continue. During the droughts of 1913-1914 and 1972-73 Lake Chad was reduced to a depth of one and two meters for most of its surface with a maximum of four meters. Thus, projects where water is to be collected in large surfaces increase the losses of water in areas where sunshine hours are long and rainfall rates small. As E. A. Olofin says:

> Of all the climatic variables in this zone, it appears that evapotranspiration is the greatest constraint to water resource development(17).

In such zones keeping the water underground until the time that is to be used reduces the evapotranspiration and economizes what in those areas is a scarce resource. Therefore pumping represents a more rational alternative.

Ground water in Nigeria appears to be free of chemical or other contamination. In contrast with surface water, specially the rivers, which are subject to a large content of sedimentation during the rainy season when most of the flow occurs, the cost of purification would be near zero. Ground water would be therefore suitable for domestic, industrial and agricultural (livestock watering and irrigation) consumption without any additional cost except for the cost of pumping. The United Nations, in its hand pump study, concludes that the cost of surface water purification plants would bring the budget beyond the limits of financing parameters in rural sectors.

5.5 Village Income

In order to assess the feasibility of selling PV pumps, the problem of financing them ought to be addressed. As it was mentioned above, in Nigeria the state governments have the responsibility of planning and financing water supply systems. During the oil boom of 1973 and up to 1979 the Federal Government shared its oil revenues with the states, giving them sources of revenues other than taxation to finance some of these programs. After 1982 nevertheless oil revenues declined drastically and government had to cut down on all types of expenditures.

In the present analysis we assume first that the farming sector will have to be able to finance its water supply projects on their own directly through some type of communal financing, or indirectly through taxes collected by the state government. In the second place, we follow the United Nations guidelines of assuming that villages should be able to pay about 5% of their subsistence income for water supply systems.

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(17) E. A. Olofin, op. cit., p. 35.

In deriving income and population figures for the agricultural sector in Nigeria, statistics from the last World Development Report from the World Bank will be used. Although government collection of statistical data has improved in the last few years, information from the agricultural sector has not kept up with this trend. The last officially accepted census dates back to 1963. Estimates of population have been made thereafter on figures from this 1963 Census extrapolated with estimates of population growth rates in the agricultural sector. One can expect a high degree of disparity among different estimates, based on different assumptions about the population rates of growth.

The World Bank estimates the population of Nigeria for 1985 at 99.7 million people with 70% of them living in the agricultural sector. These estimates would give a rural sector of about 69.79 million people. Most of the rural population consists of smallholders farm families estimated between 5 to 6 million(18).

The same difficulties are found in deriving income for farmers and its distribution. We follow the methodology of Diejomaoh and Anusionwu in their studies of income distribution in Nigeria. The Gross Domestic Product for Agriculture in 1985 was $27,108 millions according to the World Bank. If we assume a rural population of 70 million this would give an income per capita of $387.14 for the same year. These estimates would tend to underestimate the income produced in the agricultural sector since rural families engage in other productive activities besides agriculture. Peter Matlon in a study of three villages in Northern Nigeria found that rural families, whose primary oocupation was farming, derived between 20% to 40% of their family income in off-farm employment, depending on the income stratum of the family. Income distribution would change from village to village, but there seem to be a lesser degree of income inequality in the rural than in the urban sector.

To determine whether investing in a PV pump would be a rational economic choice in villages whose income per capita is similar to the estimated figure of $387.14 dollars per year, the analysis of the Net Present Value (NPV) of investment will be used. The value of the income stream of benefits to be derived from the operation of a PV pump for village water supply is made equal to 5% of the per capita income of the population per year. The NPV per villager then will be equal to $15.35 per year, or $1.61 per month. This means that a village of 300 people for example will be able to afford a loan whose monthly payment is equal to 300 * $1.61 or $483 per month. The number of years of the loan should be equal to the life of the PV pump. A pump, for example, whose life is expected to be 15 years, could sustain a loan for fifteen years. In the table below several values for different years and for different size villages are estimated. The interest rate is

(18) H. Nelson, op. cit., p. 145.

taken from the nominal interest rates of banks in Nigeria in 1985 for lending rates(19).

LOAN TERM (In Years)	INTEREST RATE	VILLAGE SIZE	MAXIMUM LOAN AMOUNT
15	9.5%	300	$46,254.00
20	9.5%	300	$51,816.00
30	9.5%	300	$57,441.00
15	9.5%	600	$92,508.00
20	9.5%	600	$103,633.00
30	9.5%	600	$114,883.00

Since the income has been estimated on per capita basis, the analysis can be extrapolated to any size village. The price of the pump designed within the parameters of this report would be in the neighborhood of $15,000. This would mean then that, for example, for a 15-year loan, i .e. the loan with the highest monthly payment, a village of 300 people would have to pay a monthly payment of $156.63 , which would be not 5% but 2% of their income.

It might be concluded then that the use of photovoltaic water pumps within the parameters of the report presents a viable alternative in Nigeria. Ground water resources are abundant and within reach, even in the drier northern zone. These resources are yet far from being fully utilized according to information given on consumption of water. And, finally, the financing of PV water pumps is well within the limits that international agencies have derived as standards for rural water projects. It must be concluded then that we can agree with Nigerian studies that affirm that water resource development is primarily a management problem.

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(19) The figure represents the lending rate, from Table 25, World Bank, 1987. World Development Report 1987. New York: Oxford University Press.

Table 5-1 Monthly average rainfall in Nigeria through 1980 to 1984

Millimetres

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
LAGOS	46.6	16.5	39.5	131.3	310.9	514.2	146.7	125.7	170.2	99.3	68.1	0.4
IBADAN	1.6	27.0	15.8	99.0	164.4	190.0	113.5	171.3	141.7	177.7	20.1	10.4
BENIN	34.0	55.9	103.3	136.0	244.0	210.6	228.8	146.5	302.8	236.8	28.4	8.0
ENUGU	7.8	20.8	32.7	70.2	252.6	191.3	254.0	171.7	364.2	181.6	18.6	0.8
PORT-HARCOURT	38.3	26.2	100.7	142.0	271.4	36.5	311.7	237.7	374.9	273.4	102.0	46.7
CALABAR	27.1	19.1	115.2	164.5	332.0	469.2	427.8	467.8	400.9	48.2	113.3	26.7
SOKOTO	0.0	0.0	0.2	1.8	29.6	96.3	176.4	188.6	58.1	7.7	0.0	0.0
KADUNA	0.0	0.0	2.0	66.4	124.3	153.2	231.6	240.8	173.3	27.7	2.2	0.0
KANO	0.0	0.0	0.0	9.8	55.8	73.7	168.7	260.1	79.2	9.2	0.0	0.0
MAIDUGURI	0.0	0.0	1.9	9.3	26.8	57.8	141.6	105.0	82.4	1.1	0.0	0.0
JOS	0.0	4.5	10.8	78.9	191.3	19.8	299.4	285.3	130.2	36.3	0.0	0.0
ILORIN	2.0	14.1	39.7	91.2	181.7	178.5	113.9	188.8	235.9	139.8	1.1	37.5
YOLA	0.0	0.0	0.0	60.0	120.1	142.6	227.7	219.3	142.8	37.0	0.0	0.0
OWERRI	42.5	9.0	77.6	117.6	300.0	319.5	307.4	239.7	558.5	72.3	31.6	19.4
MINNA	0.0	0.0	3.3	35.7	94.7	135.4	249.7	281.2	174.9	94.9	0.0	0.0
ONDO	2.4	43.7	80.2	166.2	153.4	254.1	170.4	150.4	257.3	174.7	37.2	11.0
BAUCHI	0.0	0.0	3.3	16.9	91.3	164.0	294.2	252.5	132.9	22.6	0.0	0.0
MAKURDI	4.4	0.0	19.9	67.5	156.1	597.7	272.3	220.7	193.5	76.2	0.8	0.0
ABEOKUTA	0.0	0.0	7.0	75.3	214.0	207.8	131.9	38.3	150.8	8.9	32.8	27.5

Source: Department of Metereological Services, Lagos.

Table 5-2. Monthly average evaporation through 1981 to 1984

Millimetres

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
LAGOS	3.8	4.0	3.8	4.0	2.3	2.1	1.4	2.0	2.1	2.3	2.8	2.6
IBADAN	8.8	7.2	6.1	4.3	3.2	2.3	2.1	2.1	2.2	2.5	3.8	4.4
BENIN	4.6	4.3	3.5	2.7	2.1	1.7	1.4	1.4	1.5	1.8	2.6	2.0
ENUGU	10.0	10.3	7.7	6.0	3.7	2.9	4.1	2.5	2.3	2.7	4.5	5.5
PORT-HARCOURT	5.7	5.0	4.1	3.1	2.1	1.8	1.3	7.8	6.0	1.6	3.2	2.9
CALABAR	4.4	4.2	3.4	2.4	1.9	1.7	1.4	1.4	1.6	1.7	2.2	2.8
SOKOTO	18.5	21.8	21.9	20.5	13.3	12.2	7.1	-	6.5	17.8	18.4	-
KADUNA	15.4	17.4	16.2	11.0	5.5	2.9	2.6	2.4	8.5	5.8	12.0	13.3
KANO	13.8	17.4	19.8	18.0	13.4	10.5	6.6	4.5	5.8	13.2	14.5	14.1
MAIDUGURI	12.3	12.0	10.1	13.8	11.6	3.1	2.4	2.3	2.7	3.1	5.8	6.5
JOS	13.0	14.3	13.0	8.8	3.4	2.8	1.9	19.0	2.7	5.8	10.2	11.3
ILORIN	10.5	10.0	8.5	6.0	3.9	3.3	2.9	3.0	2.5	3.2	5.9	5.5
YOLA	10.1	12.3	13.0	10.8	6.1	4.1	2.6	2.5	2.7	4.0	7.6	9.5
OWERRI	6.8	5.9	5.0	4.0	3.0	2.6	1.7	1.7	2.1	2.3	3.6	3.8
ONDO	6.1	6.1	4.9	3.4	2.8	2.3	2.3	2.5	1.8	2.3	3.1	3.4
BAUCHI	10.4	10.9	14.9	12.9	7.2	4.6	2.9	2.5	2.9	6.0	9.1	9.8
MAKURDI	14.9	13.2	13.1	9.9	4.7	3.1	2.5	2.8	2.8	3.4	4.8	-
ABEOKUTA	6.3	5.3	4.5	2.9	2.0	1.5	4.5	1.5	1.6	2.2	2.7	-

Source: Department of Metereological Services, Lagos.

Table 5-3 Monthly average sunshine hours through 1981 to 1984

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
LAGOS	4.7	5.2	5.1	6.3	5.0	3.6	3.0	2.6	3.7	4.5		
IBADAN	4.2	5.0	5.4	5.5	5.7	4.6	3.4	2.5	3.4	4.7	6.6	5.7
BENIN	4.5	5.8	5.0	6.2	5.5	4.5	3.4	2.7	3.6	4.8	5.8	
ENUGU	5.3	6.3	5.4	6.2	5.9	5.2	3.6	2.8	3.7	4.7	6.3	7.1
PORT-HARCOURT	4.1	4.7	3.5	5.3	4.4	2.9	1.8	1.1	2.2	3.1		
CALABAR	3.0	3.2	3.1	3.8	3.6	2.7	1.7	1.3	1.9	2.8		
SOKOTO	9.1	7.5	9.2	7.4	7.5	7.2	7.3	6.1	7.9	7.9	6.2	8.2
KADUNA	7.5	8.3	7.7	8.7	8.0	7.1	5.4	6.0	7.1	7.2	8.0	9.2
KANO	6.8	7.4	6.9	8.0	6.2	7.8	7.4	7.7	7.6	7.1	8.2	
MAIDUGURI	7.4	6.9	7.9	6.9	-	-	-	-	-	8.0	-	-
JOS	8.6	8.6	7.3	7.2	6.2	6.2	5.2	5.3	5.6	7.0	6.9	9.1
ILORIN	7.2	6.7	6.5	6.8	6.7	5.7	3.9	3.4	4.7	5.6	5.2	4.5
YOLA	6.9	6.4	6.7	7.6	6.9	6.9	6.2	6.2	7.1	7.6	8.0	8.4
OWERRI	3.8	5.2	5.2	5.4	4.4	3.0	2.5	1.9	3.0	4.1	5.4	6.3
ONDO	5.5	6.4	5.6	6.1	5.4	4.5	3.2	2.6	3.3	5.1	6.4	
BAUCHI	4.7	6.6	6.9	4.8	7.2	7.2	6.8	6.8	6.7	7.7	8.8	7.0
MAKURDI	5.2	6.8	5.6	7.0	6.5	5.6	4.3	4.6	4.9	5.8	7.5	
ABEOKUTA	3.2	5.1	4.3	5.6	5.9	4.3	3.0	2.2	3.1	4.1	5.7	5.6

Source: Department of Metereological Services, Lagos.

6. Optimal Design Method

An overall approach to the design for cost optimization of a stand-alone PV system was chosen and developed in such a way that expansion of the method to cases other than those considered here would be relatively easy. An "expert systems shell" was developed and utilized for a PV water pumping system. For a given well depth, daily water requirement, daily solar insolation, and the costs of each of the components of the PV system both imported and locally produced, the design algorithm chooses the appropriate pump type, the least-cost components, and the least-cost combination of array size and water storage for a given loss-of-load probability. The estimated overall initial cost of the system is the final output of the method.

In the following section, a brief overview of expert systems and knowledge bases will be given. The algorithms for pump type choice, local or import component choice, and least-cost array and storage size calculation are discussed in Section 6.2. The estimated costs of the system components used in the algorithm are also presented in Section 6.2. The results of applying the design method for a typical case in northern Nigeria are presented in Chapter 7.

6.1 Expert Systems Approach

From a philosophical perspective, an expert system is one in which the knowledge of experts is contained in a systematic way such that it is accessible to others, usually through a computer program. From an operational point of view, an expert system is a collection of rules organized in such a way that if a user of the system inputs some premises or facts, the system will present one or more conclusions.

The rules are generally of the form of "if...then...else." For example, a rule could be the following: "if the hydraulic head is greater than 30 m and the water flow rate is less than 13 cubic meters per day, then the pump type should be volumetric jack pump." The rules can be placed directly into the expert system program, or they can be inferred by the program from a "knowledge base" of if-then-type cases (i.e., "expert" decisions). The expert system will search through the rules to find the result or conclusion in response to the information or premises given.

For a more thorough discussion of expert systems, many books are available, from the introductory [e.g., Frenzel, 1987] to the more sophisticated [e.g., Gale, 1986]. A relatively inexpensive, yet powerful expert system shell was utilized in this study: VP-EXPERT, Version 1.2 [Sawyer, 1987], which runs on an IBM PC or compatible. A shell is generally easier to use than specialized expert system or artificial intelligence languages, such as PROLOG and LISP [Frenzel, 1987].

The main advantage of the expert system approach in this study is the flexibility and expandability of the method to incorporate many design rules, optimization routines, and data for a wide variety of PV system types and for several countries. The expert system program developed for this study is limited by the available data that we were able to gather within the scope of the study. This expert system program can be extended to cover many more PV system types, local countries, etc.

Another important advantage for us in this approach was the ability to utilize systematically the expertise of several people experienced in various aspects of PV system design, manufacture, economics, etc. This expertise was obtained through the literature and personal communication, as noted in the next section.

An additional advantage of this approach is the ability of the expert system to estimate confidence levels of the final result(s), based on the confidence levels of the various rules used in the program.

6.2 System Design Rules and Algorithms

Three basic design algorithms were incorporated into the expert system program: pump type selection, least-cost component selection, and optimal array and storage sizing. These algorithms are described below. The actual program (OPTIMAL) was written for the VP-EXPERT shell and is listed in Appendix D.

6.2.1 Pump Type Selection

The pump type selection criteria utilized in the design method is that given in Matlin et al. [1986] (revised and republished by Sandia [1987]). Basically, five different pump types are selected based on the given hydraulic head and water flow rate. For example, for heads of less than approximately 6 m and for daily flows greater than 25 cubic meters, dc self-priming surface-mounted centrifugal pumps are recommended. The other pump types are dc vertical turbine, dc submersible, volumetric jack, and hand.

The pump electrical load is computed by dividing the energy needed to lift the weight of water through the head by the estimated pump efficiency:

$$L = \frac{h f \rho g}{\phi K} \quad \{6-1\}$$

where L is the load (Wh/day),
h is the height (m),
f is the flow (m^3/day),
ρ is the density of water (kg/m^3),
g is the acceleration due to gravity (m/sec^2),
ϕ is the efficiency of the motor-pump,
and K = 3600 kg m2/sec2 (or J) per Wh.

The efficiency estimates are set at 20% for centrifugal pumps and 40% for all other pump types. These estimates were based on manufacturers' specifications. The exact pump selection rules are given in the first part of the program listing in Appendix D.

6.2.2 System Component Selection

The next step in the optimal design method is to select between the imported and locally produced components on the basis of cost. It is obvious that in the optimal tradeoff between array size and storage size to achieve a desired loss-of-load probability, the least-cost array-related components (on a per peak watt basis) and the least-cost storage-related components (on a cubic meter of water basis) will lead to the overall minimum-cost system. In other words, in this case two local minimums will lead ultimately to the global minimum.

The following components are included in the selection process: cells, modules, array structure and wiring, maximum power tracker, motor-pump set, and water storage. Battery storage is not included in the algorithm because of the high cost relative to water storage. Wafers are assumed to be imported because there appears to be no present capability of producing them in Nigeria. The algorithm has an additional constraint that if local cells are less costly than imported cells, then local modules are chosen also (to avoid the undesirable choice of local cells and imported modules).

A fixed array is assumed. The algorithm could be easily extended to take into account the cost/benefit of passive tracking devices.

Several PV water pumping design guides were consulted in the process of choosing which components to include [Matlin et al., 1986; IT Power, 1984; Sandia, 1987]. The design in this method is limited to component selection and sizing. Details, such as piping system layouts, structural footing sizing, bolt sizing, are not included. Additional details of the design process could be added relatively easily, however. The level of detail used in this study appears to be appropriate for what is essentially a feasibility study.

The estimated costs of each component are given in Table 6-1. The various factors that go into each component cost are listed there. The rationale for the cost estimation process is given in Chapter 4 of this report. It should be noted that the cost estimates of many of the factors that go into the component costs are VERY approximate at this point and that any results based on these costs should be interpreted accordingly.

The Nigerian cost estimates were difficult to obtain. We had one member of our research team (Dr. Iheanacho Nwokogba) in Nigeria during late December and early January. He is a native of Nigeria. He obtained cost and industrial capacity information from the government and had a relative who is a well driller put together information for the project. This latter information is listed in Table 6.1 with "Paho Ltd." as the information source. We also received local cost information from L.O. Ejiofor with the Nigerian Federal Ministry of Industries. This information was in general consistent with the Paho data.

The costs of the components are accessed by the design program through a spreadsheet file (LOTUS 1-2-3 compatible). The costs of all the components except the storage are added together to obtain a total array-related cost in US $ per peak watt (W_p). The part of the cost that will remain in the local country is computed and reported separately. All costs at this point are initial costs and do not include financing costs, maintenance and replacement costs, etc.

6.2.3 Array and Storage Sizing

The design method contains an algorithm for sizing the array and storage to achieve a minimum initial cost for a given loss-of-load probability. The combinations of storage and array size for a given loss-of-load probability (LOLP) were taken from Klein and Beckman [1987]. These combinations also change with clearness index (K_T). A loss-of-load probability of 1% was chosen for this study. It should be noted that the loss of load considered here is that due to weather variability only (i.e., lack of sufficient solar insolation for several days) and is not that due to component failures and the like. Also a constant daily load is assumed in the LOLP prediction method [Klein and Beckman, 1987]. Lower LOLP predictions have relatively high confidence intervals (i.e., high uncertainties) associated with them because of relatively short periods of solar insolation data upon which they are based [Bloom and Duffy, 1988].

Combinations of storage and array size for a clearness index of 0.5 are used in the design method here and are illustrated in Figure 6-1. This clearness index corresponds to the December recorded average solar insolation (5.8 $kWh/m^2/day$) in Samaru in northern Nigeria [Griffiths, 1977]. The horizontal axis in Figure 6-1 is given as SLR or solar-to-load ratio, which is defined as follows:

$$SLR = \frac{\bar{H} W_p}{L} \qquad \{6-2\}$$

where $\bar{H}$ is the average daily worst month horizontal insolation ($Wh/m^2/day$ divided by 1000 W/m^2),
W_p is the array size in peak watts (rated at 1000 W/m^2 insolation),
and L is the load of the pump (Wh/day).

The cost optimal combination is obtained analytically in the following way: Assume the cost of the system is equal to the following:

$$C = W_p C_A + S C_S \qquad \{6-3\}$$

where C_A is the array-related cost ($\$/W_p$),
S is the storage size (m^3)
and C_s is the cost of the storage ($\$/m^3$).

With Equation 6-2, {6-3} can be written:

$$C = \frac{SLR \cdot C_A L}{\bar{H}} + B f C_s \qquad \{6-4\}$$

where B is the storage size in days of load (S/L).
and f is the flow (m^3/day).

Optimizing the cost with respect to SLR allows us to set the derivative of cost with respect to SLR to zero:

$$\frac{\partial C}{\partial (SLR)} = \frac{C_A L}{\bar{H}} + \frac{\partial B}{\partial (SLR)} f C_S = 0 \qquad \{6-5\}$$

Rearrangement of {6-5} yields:

$$\frac{\partial B}{\partial (SLR)} = -\frac{(C_A L) \div \bar{H}}{f C_S} \qquad \{6-6\}$$

for the least cost system. In other words, the minimum-cost combination of storage and array size corresponds to the point on the curve of storage vs. array size (or more specifically B vs. SLR) where the slope of the curve is equal to $\partial B/\partial(SLR)$ in Equation 6-6.

In the expert system program, four combinations of B and SLR are used. If the slope computed with (6-6) is less than the line slope between two points but greater than the line slope adjacent to the left, then the point to the left of the first line is taken as optimal. The exact procedure is given in the program listing in Appendix D. In other words, the closest of the four points is chosen as optimal. The number of points could obviously be expanded for greater precision as greater input data accuracy warrants.

The results of applying the expert system method to what appear to be typical northern Nigeria conditions are presented in the next chapter.

Table 6-1.

Cost Estimates for PV Components of a Typical Water Pumping System For Use in Optimal PV System Design for Export

Estimated cost to installer(s) (US$):

(Assumption: approx. systems per year in northern NIGERIA: 500

Component	Cost	Units	Source	Comments
CELL:				
Cells--US	4.00	$/Wp	supplier	personal communication
Shipping	1.00	$/lb	estimate	via sea
Duties	0.40	$/Wp	D of Comm	Dept. Comm.; 10%
Cell weight	0.10	lb/Wp	estimate	
Import_cell	4.50	$/Wp	(includes	$0.40 to local country)
Cells--local:				
Machines	0.54	$/Wp	mfgr.	7 yr. amortization
Factory bldg.	0.34	$/Wp	Means	Cost, 7 yr. amortization
Labor--local	0.05	hr/Wp	mfgr.	11 factory workers, 1/2 engineer
Labor cost	0.49	$/hr	Paho Ltd.	11 laborers, 1/2 eng., 20% admin.
Raw material	3.50	$/Wp	supplier	Import blank wafers
Local_cell	4.40	$/Wp	(includes	$0.37 to local country)
MODULE (NOT INCLUDING CELL):				
Modules--US	3.00	$/Wp	mfgr.	From distributor (less import cell)
Shipping	7.36	$/ft3	shipper	Bruning
Duties	0.30	$/Wp	D of Comm	0
Module volume	0.11	ft3/Wp	Trisolar	Model JP1009-3 System
Import_module	3.98	$/Wp	(includes	$0.30 to local country)
			(includes credit for shipping cells above)	
Modules--local:				
Semi-automated production line	0.44	$/Wp	mfgr.	machinery, 7 year amortization not incl. glass, laminate, cells including shipping
Factory bldg.	0.34	$/Wp	Means	Cost, 7 yr. amortization
Labor--local	0.23	hr/Wp	mfgr.	11 factory, 1 technical
Labor cost	0.49	$/hr	Paho Ltd.	11 laborers, 1/2 eng., 20% admin.
Glass--local	0.23	$/Wp	Paho Ltd.	local
Framing, etc.	0.50	$/Wp	estimate	metal, chemicals, laminate, jct. box
Local_module	1.61	$/Wp	(includes	$1.18 to local country)
ARRAY STRUCTURE (NOT INCLUDING MODULES):				
Import:				
Structure	0.25	$/Wp	estimate	aluminum
Wiring, boxes	0.05	$/Wp	estimate	copper (120 V)
Shipping	7.36	$/ft3	shipper	ocean
Structure	0.02	ft3/Wp	Trisolar	
Duties	0.03	$/Wp	D of Comm	Dept. Comm.; 10%
Labor--local	0.08	hr/Wp	Ga Tech	electrician and laborer
Labor cost	0.76	$/hr	Paho Ltd.	laborer(.6), carpenter, elec., heavy equip., 20% admin.
Import_array	0.51	$/Wp	(includes	$0.09 to local country)
Local:				
Structure	0.16	$/Wp	Paho Ltd.	steel (200 ft for 500W, $.4/ft)
Wire, boxes	0.03	$/Wp	estimate	
Labor--local	0.17	hr/Wp	Ga Tech	electrician and laborer

Labor cost	0.76 $/hr	Paho Ltd.	laborer(.6), carpenter, elec., heavy equip., 20% admin.
Local_array	0.32 $/Wp	(includes	$0.32 to local country)
INTERFACE:			
(Max Power Tracker)			
Local:	4.00 $/Wp	estimate	expensive to make electronic equip. locally
Local_m_p_tracke	4.00 $/Wp	(includes	$4.00 to local country)
Import:	2.00 $/Wp	mfgr.	oversized, limited selection
Shipping	0.10 $/Wp	shipper	ocean
Duty	0.20 $/Wp	D of Comm	0
Import_m_p_track	2.30 $/Wp	(includes	$0.20 to local country)
FENCE:			
Import:	3.00 $/Wp	supplier	chain link, 8 ft;.2 ft/Wp
Shipping	7.36 $/ft3	shipper	ocean
Fence volume	0.01 ft3/Wp	estimate	
Duty	0.30 $/Wp	D of Comm	0
Labor--local	0.02 $/Wp	Paho est.	0.05 hr/Wp * $.41/hr, laborer
Import_fence	3.37 $/Wp	(includes	$0.32 to local country)
Local:	0.75 $/Wp	Paho est.	Wood, 2 m; 0.06m/Wp; $6.25/m2
Labor--local	0.03 $/Wp	Paho est.	0.05 hr/Wp * $.52/hr, carpenter
Local_fence	0.78 $/Wp	(includes	$0.78 to local country)
MOTOR-PUMP SET A:			
("jack" volumetric pump, d.c. motor)			
Local:	8.64 $/Wp	Paho Ltd.	$4200 pump 10 m3/day + $120 motor 1 hp for 500 Wp (pump assembled locally; parts imported)
Local_pump_jack	8.64 $/Wp	(includes	$4.32 to local country--1/2 imported)
Import:	2.00 $/Wp	Matlin	PV Water Pumping Guide
Shipping	1.30 $/Wp	shipper	600 pound pump, Trisolar
Duty	0.20 $/Wp	D of Comm	0
Import_pump_jack	3.50 $/Wp	(includes	$0.20 to local country)
MOTOR-PUMP SET B:			
(Submersible d.c. motor)			
Local:	5.23 $/Wp	Paho Ltd.	$7500 pump 30 m3/day + $350 motor for 1500 Wp (pump assembled locally; parts imported)
Local_pump_subm	5.23 $/Wp	(includes	$2.62 to local country--1/2 imported)
Import:	0.60 $/Wp	mfgr.	1 hp, $300, 500 Wp
Shipping	0.13 $/Wp	shipper	based on volume, 8.6 ft3; ocean
Duty	0.06 $/Wp	D of Comm	0
Import_pump_subm	0.79 $/Wp	(includes	$0.06 to local country)
STORAGE TANK:			
(including pipes, valves, etc.)			
Local:	30.00 $/m3	guess	fiberglass or concrete, site made
Size		variable	based on loss-of-load probability
Labor--local	0.69 $/hr	Paho Ltd.	aver. construction worker, 20% admin.
Labor time	6.00 hr/m3	estimate	
Local_storage	34.14 $/m3	(includes	$34.14 to local country)
Import:	207.00 $/m3	DAG	mfgr., plastic, 7000 gal., 27 m3
Size		variable	based on loss-of-load probability
Shipping	260.00 $/m3	shipper	ocean, from New York

Duty	20.70 $/m3	D of Comm	0
Labor--local	0.69 $/hr	Paho Ltd.	aver. construction worker, 20% admin.
Labor time	2.00 hr/m3	estimate	
Import_storage	489.08 $/m3	(includes	$22.08 to local country)
WELL DRILLING:			
Local-only:	387.10 $/m	Paho Ltd	per meter of head, adjusted to well depth (based on 62m well in Sokoto province with 25% adjustment for well depth > head)
Local_well	387.10 $/m		per meter of head (see NOTE below) (NOTE: add 25% or more to static water table for head estimate to allow for drawdown.)
OPERATION and MAINTENANCE:			
O & M	0.20 $/Wp/yr	Matlin	PV Water Pumping Guide
REPLACEMENT:			
Pump at 10 yrs	0.20 $/Wp/yr	Matlin	PV Water Pumping Guide (variable, depending upon type)

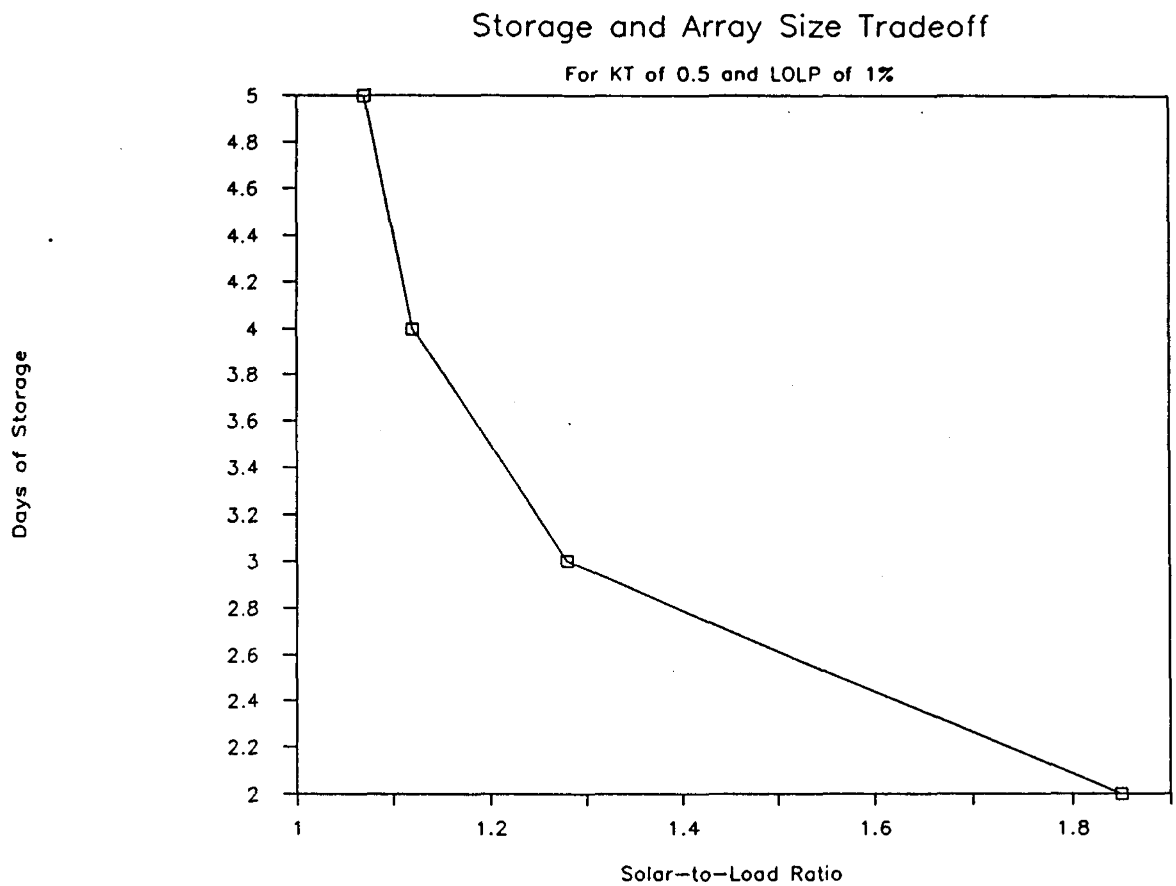

Figure 6-1. Storage and Array Size Combinations for a loss-of-load probability of 1%.

7. RESULTS

The results of applying the expert system design method described in Chapter 6 are presented in this chapter. A set of inputs is used which reflect typical conditions in northern Nigeria.

7.1 Initial Cost Estimate Results

A static water table depth of 26 meters appears to be typical at some distance from a river, where water presumably is in demand, as discussed in Chapter 5. An extra 25% is added to the water table depth to obtain an approximate hydraulic head (to allow for drawdown of the water table). Another 25% is added to the hydraulic head to obtain a rough estimate of the well drilling depth for costing purposes. More precise estimation of drawdown and well depth would require detailed knowledge of soil and substrate properties at a particular location in Nigeria and is beyond the scope of this study. A drinking water flow rate sufficient to support 300 people is used. This population is within the range of cost-effective applications found by Meridian [1987a]. A per capita water consumption of 45 liters per day is assumed.

An average December solar horizontal irradiation value of 5.8 $kWh/m^2/day$ for the town of Samaru in northern Nigeria [Griffiths, 1977] was used in the calculations. All the costs given in Table 6-1 were used.

The results are summarized below:

The optimal pump type is dc submersible.
The pump electrical load is estimated at 2986 Wh/day.

The selected system components include:
imported wafers
local cells
local modules
local array structure
local fence
imported maximum power tracker
imported pump
local storage.

System array-related cost estimates totaled 10.20 $\$/W_p$, of which 3.04 $\$/W_p$ remains in the local country.
Storage-related costs were estimated at 34.14 $\$/m_3$, all of which remains in the local country.

The optimal array size is estimated at 577 watts peak.
The optimal water storage size is estimated at 54 cubic meters (four days storage).

The total array-related cost is estimated at $5,885, of which $1,638 remains locally. The total storage-related cost is estimated at $1,843.

The well cost is estimated at $12,580. The total system cost is therefore $20,309.

It should be noted that these cost figures and choices of components are based on some very rough cost approximations. These results should be interpreted accordingly. The design results should be considered as appropriate for a feasibility study, not for final design specifications. Such subtleties as the difference in efficiency, maintainability, and reliability between the locally-produced components and imported components have not been taken into account.

Nevertheless, these preliminary results are encouraging. If the above total cost of typical PV water pumping system is compared to the estimated proportion of village income that can be expended on drinking water, we see that the cost is less than the available income, as discussed in the next section.

7.2 Results for System Lifetime Costs

The calculations of Section 6 show a potential for substantial reductions in the cost, and in the requirements for foreign exchange, of solar pumping systems suitable for rural village water supply and irrigation of small plots.
Reducing the cost of solar pumps should increase demand for two reasons: smaller villages or villages with lower income levels will be able to finance the purchase of pumps, and, since solar power competes with hand-pumps and diesel-powered pumps, the range of water volumes for which these systems are cost-effective may increase. Both effects can be illustrated in Figure 7.1, following. This presentation, which is adapted from Meridian [1987], shows the cost per liter of water for the three types of systems as a function of capacity required, expressed as village size. The effect of increasing local manufacturing content is represented by the dashed curve: for any given level of available income, additional (smaller or lower income) villages will be able to finance the water supply system.

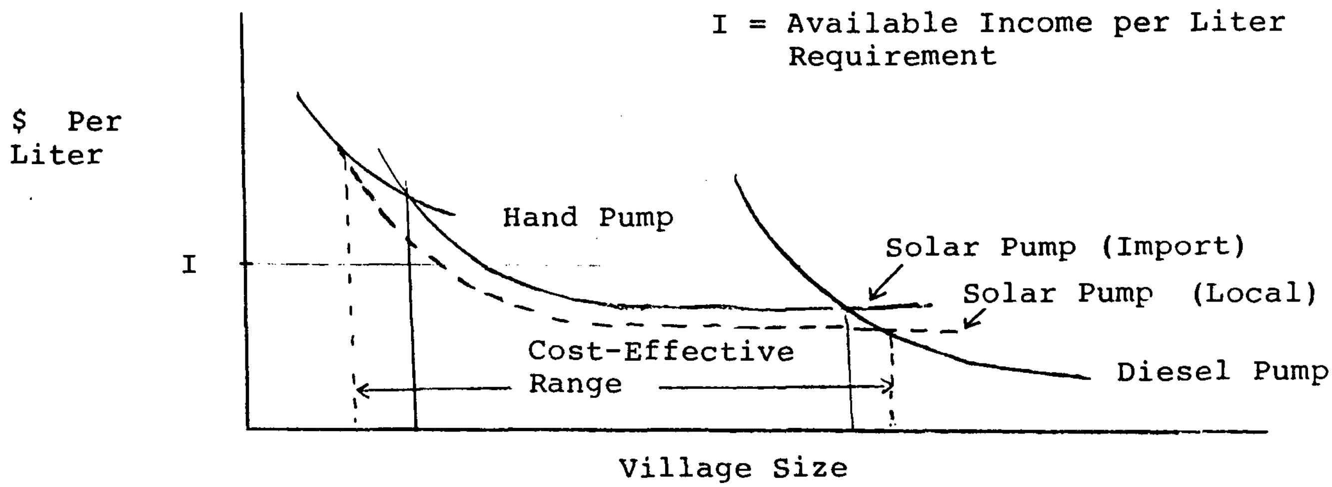

Figure 7.1 Qualitative comparison of water cost and village size.

Figure 7.1 is a conceptual tool. To illustrate the possible impact of increased local manufacture, the calculations of initial costs from Section 6 are converted to the annual cash flows required to finance the investment and operating costs. These can be compared to the estimates of rural incomes and cash availability developed in Section 5.

Table 7-1 presents total investment and annual costs for the cases of complete import of the pumping system, local manufacture of the system to the extent feasible, and an optimal (i.e. cost-minimizing) manufacturing policy. The columns of Table 7-1 relate to the following cases:

CASE I -- Optimal local manufacture (Cells and the Maximum Power Tracker are imported). Well-drilling is <u>not</u> financed by the village: either there is a pre-existing well or the well is provided under a separate governmental program.

CASE II -- Optimal local manufacture as in Case I; well-drilling <u>is</u> part of the cost to the village.

CASE III -- 100% local manufacture except for cells and Max. Power Tracker. Well not included.

CASE IV -- Local manufacture as in Case III, well <u>included.</u>

CASE V -- System 100% imported (except for storage tank). Well not included.

CASE VI -- System 100% imported as in CASE V with well included.

Table 7-1

Investment and Annual Operating Costs for Solar Pumping Systems

	I	II	III	IV	V	VI
Investment						
Array	$ 5,430	$ 5,430	$ 6,410	$ 6,410	$ 8,458	$ 8,458
Storage	1,844	1,844	1,844	1,844	1,844	1,844
Pump	456	456	3,018	3,018	456	456
Well	N.A.	12,581	N.A.	12,581	N.A.	12,581
Total	7,730	20,311	11,272	23,852	10,758	23,389
For. Exchange Required	4,248	4,248	4,089	4,089	8,124	8,124
Annual Loan Service	970	2,272	1,261	2,668	1,203	2,616
Annual O & M	115	115	115	115	115	115
Total Annual Cost	970	2,387	1,169	2,783	1,318	2,731

NOTES:

Assumptions: 9.5% Rate of Discount (World Bank lending rate).
Pump and motor replaced at 10 year intervals.
20 year life for photovoltaic components.
Village size 300 persons.
Water requirement 45 liters/person/day.
Water depth 32.5 meters (well 41 meters).

"Foreign Exchange Required" is total first-round expenditures on imports

Maximum Local Production (Cases III and IV) and Import (Cases V and VI) investment costs are based on the Case I and II design: that is, the array, storage and pump sizes were not reoptimized for those specific cost inputs. Consequently investment costs for Cases III through VI are somewhat overstated relative to Cases I and II. However, the error involved is not significant.

The annual charges displayed in Table 7-1 (bottom line) should be compared with the income estimates for rural villages derived in Section 5. These are repeated here:

	Monthly	Annually

5 %	Total Village Income	$ 483	$ 5,796
2 %	" " "	193	2,318

As noted in Section 5, even small villages seem well able to finance their water supplies by the standards for low income areas suggested in World Bank and United Nations studies of this problem. A policy of local manufacture will nevertheless make these systems more affordable, and may expand somewhat their cost-effective range in comparison with diesel and human power.

Note that "optimal" systems (Cases I and II) are substantially cheaper than either systems that maximize local production without regard to cost (Cases III and IV) or systems that are mainly imported (Cases V and VI).

Capital outlays and financing requirements are substantially lower if we assume the well is provided by the central government, as appears to be a possibility in light of the active drilling program now in progress under World Bank and Nigerian auspices. It should also be recalled that both drilling costs and pump costs would rise considerably for deeper wells (well-drilling is priced at $387.10 per meter in our cost analysis). It would seem that most wells are at or less than 41 meters, but large numbers will no doubt be deeper.

While no accurate estimate of the potential number of solar pump applications was possible with the available information, Nigeria's large rural population,the large underdeveloped land area and the high priority now assigned to rural development suggest that ultimate demand will be substantial. This point is reinforced by Nigeria's very active interest in water programs.

Many of the bore holes presently being drilled are presumably intended for hand pump applications, but as pointed out in Section 5, on effect of increasing development of rural areas is reduction in unemployment or idle time, with the effect of raising the opportunity cost of labor and thus the cost of hand-pumping.

The design method also provides information about the share of total system expenditures going to local industry, as opposed to the exporting country (in this case the U.S.). These data were used to derive estimates of the amount of foreign exchange required for the first-round expenditures for system components and materials. These estimates also appear in Table 7-1, and indicate that not only are the "optimal systems" (Cases I and II) considerably less expensive than those which maximize in-country production, but their <u>first-round</u> foreign exchange impact is only slightly larger. Purchase of systems that are mainly imported (Cases V and VI) incur a substantial foreign exchange penalty, however.

These results are limited, in that only a single village situation was investigated and the cost-effectiveness of solar pumping relative to other types of systems was not analyzed. However, subject to these qualifications, the results indicate that optimal designs for export will favor local manufacture of as much of the system as is feasible. There is a cost advantage from doing so, and, importantly, foreign exchange requirements are reduced and the industrialization objectives of the receiving countries are enhanced.

Some of the manufacturing technologies involved would appear to stretch and extend Nigeria's present capabilities; the more completely these capabilities are developed the lower would be the costs to Nigerians and the larger the benefits in terms of added industrialization.

8. CONCLUSIONS AND RECOMMENDATIONS

In addition to the results reported in Section 7, a number of more general conclusions and recommendations flow from this study:

1. The design methodology developed in the course of this study is quite promising. It lends itself easily to feasibility studies and can be used at comparatively small effort to test the implications of preliminary data for export planning or to design an export program. It allows easy consideration of various input data sets. Ways in which the approach might be extended for photovoltaic applications include incorporating additional design trade-offs and adding more specialized output summary and analysis routines. These might, for example, display the effect of variations in key cost or design parameters, or present cash flow profiles and financing requirements.

2. The work presented in this report is essentially a pre-feasibility study of the manufacture of solar pump systems in Nigeria. As such, it forms the groundwork for additional development of a case study of an optimal export program for Nigeria and of the benefits of the transfer of this technology to all concerned.

3. Although the data were limited and conclusions must be drawn with caution, the results do suggest that "design for export" may have important implications. In the examples explored with the design methodology and the available data, the system cost savings from optimizing local manufacturing and service participation were not large in percentage terms. However, if the advantages to the importing country are not limited to cost savings; foreign exchange savings and economic development may be equally--or more--important. Optimizing local manufacturing in this case assures that these other goals can be addressed without a cost penalty.

4. Although identifying major new markets for photovoltaic systems was not a primary objective of this study, it is apparent that Nigeria is significantly involved in water resource development and that a considerable potential exists there for water system equipment and construction services sales.

5. Actual field data are desirable, indeed essential, for planning in the manufacturing and service support areas. This is particularly true with respect to the availability and quality of components, such as pumps and motors, and labor skills. Data acquisition is time-consuming and potentially expensive. Site visits or use of local assistance is recommended.

9. ACKNOWLEDGEMENT

The authors gratefully acknowledge the technical direction of Dr. Edward Kern of the MIT Energy Laboratory; the financial support of the U.S. Department of Energy through MIT, under contract DOE-AC02-76ET20279; the U.S. PV companies which responded to our telephone survey; the institutions and companies in other countries that completed our mail survey; Lori Coakley and Sarah Williams, University of Lowell graduate assistants; and to the following for various kinds of information and general assistance: World Bank, Massachusetts PV Center, University of Lowell PV Project, Sandia Laboratory, Dept. of Energy Committee on Renewable Energy, Commerce and Trade, Dept. of Commerce Office of International Trade, United Nations Development Program, U.S. Agency for International Development, Government of Nigeria, and Solar Energy Industries Association.

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APPENDIX A.

Summary of the Telephone Survey

Not all the companies have answered all the questions (either because of the field of their interest or simply they did not want to answer). That is why there are different numbers of companies in different question groups.
The questions from the original questionnaire appear here in bold-face typing.
"NA" means, we got no answer to the question.
Numbers in the parenthesises:

First number - the number of companies that gave that answer

Second number - what percent of the first number relative to all the answering companies (in that question group)

Where there is a possibility of more than one answers to a question, naturally the percentages will not add up to 100%. Sometimes for the same number of answers there is a different percentage given, because of the different numbers of answering participants.

A./ PV stand-alone systems or components (15 companies answered these question)

A1./. What is the number and/or $ value of the systems manufactured and/or sold by your company in the last year?

Most of the companies (11 out of 15, e.g. 73%) did not give us any number, the others were:
Number of systems: 3, 6, 20, 100
$ value : $300,000, $1 million, $5-6 million and $12 million
(The number of systems - $ value data-pairs do not necessarily belong to the same company!)

A1a./ Where do you think business growth areas are?

NA (1; 7%)
By application: Rural electrification (4; 27%)
Consumer products (2; 13%)
Utilities (2; 13%)
Telecommunication (2; 13%)

Water pumping (1; 7%)
Agriculture (1; 7%)
Medical refrigeration (1; 7%)

By country: Third World (4; 27%)
India (2; 13%)
Asia - Africa - Latin America, throughout the world (each of them 7%)

A2./ What applications does your company make and/or sell?

water pumping (11; 73%)
lighting (any kind) (7; 46%)
communication equipment (5; 33%)
stand-alone generators (4; 27%)
home power (3; 20%)
refrigeration (3; 20%)
interconnection to existing grid (2; 13%)
air conditioning (2; 13%)
navigational aids (2; 13%)
marine (2; 13%)
domestic hot water, inverters, battery charging, military, billboards & advertising structures (1; 7%)
"any product that can or does use electricity is a candidate for photovoltaic power" (1; 7%)

A3./ What is your most common system?

Every kind of system, every company has different ones.

A4./ What are the components supplied overseas?

NA (6; 40%)
none (5; 33%)
everything except panels (1; 7%)
every component, the receiving country can produce (1; 7%)
depends on the order (1; 7%)
everything (they have several joint venture partners in Japan and Europe) (1; 7%)

A5./ How are the components shipped?

NA (6; 40%)
depends on the costumer's need (by sea or air) (5; 33%)
ship (3; 20%)
air (1; 7%)

A6./ Who assembles and installs the system in the receiving country?

NA (6; 40%)
receiving country (6; 40%)
manufacturer (2; 13%)
depends on the job (1; 7%)

A7./ Who maintains the system in the receiving country?

NA (6; 40%)
receiving country (7; 46%)
manufacturer (2; 13%)
[1. company: they go there and fix the system
2. " : the owner has to send back the whole system]

Warranty (usually):
NA (8; 53%)
1 year (2; 13%)
1 - 5 yrs. (2; 13%)
5 years (1; 7%)
1 - 10 yrs. (1; 7%)
10 yrs. (for modules) (1; 7%)

A8./ How are the systems financed?

NA (6; 55%)
by the local Government (3; 27%)
World Health Org., Red Cross, UNICEF, US Government, USAID, World Bank, individually (1; -%)
varies (Bank, 3rd party, lease-purchase, time-pay) (1; 7%)

A9./ What is the approximate cost of the different systems (and/or system components)?

NA (7; 46%)
average water pump system: $4-5,000
average system: $2,000
systems:

300 kW	$7/W installed	
24 MW	$2/W	"

component costs:

400 W generator	$4,130
800 W "	$6,936
tracker head	$ 980
well pumps:	
500 gal/day	$2,030
900 "	$2,730
2,000 "	$3,800

A10./ What foreign competition do you face?

NA (3; 20%)
Japan (7; 46%)
Europe (2; 13%)
England (2; 13%)
Germany (2; 13%)
none (2; 13%)
Australia; India - in the future, flat plate manufacturers (1; -%)

A11./ Do you use foreign agents, distributors and/or trading companies?

NA (5; 33%)

	Yes		No	
foreign agents	5	(33%)	4	(27%)
distributors	5	(33%)	4	(27%)
trading companies	3	(20%)	6	(40%)

B./ Manufacturing equipment (8 companies)

B1./ What PV system manufacturing equipment do you make and/or sell?

All 8 companies dealing with manufacturing equipment make and sell whole turn-key systems (plus one makes module assembly systems, and another one sells test equipment for cells, modules, arrays, simulators and individual machines as well).

B2./ Do you have a most common manufacturing system?

NA (2; 25%)
they do not have any (1; 12%)
yes, they have (5; 63%)
- three replied: 1 MW/year
- one replied: 1,2,5 & 25 MW/year
- one replied: * in line production
  * 2 R&D systems - single chamber
    - 4 chambers

B3./ What manufacturing components are typically provided by local suppliers?

NA (2; 25%)
some countries supply part of the equipment, some provide nothing (2; 25%)
none (2; 25%)
1 company buys electronics, pumping system and vacuum

chamber
1 company uses everything the receiving country can provide

B4./ Who installs and maintains the manufacturing system(s)?

NA (1; 12.5%)

Installs:	manufacturer	(4; 50%)
	receiving country	(2; 25%)
	up to the customer	(1; 12.5%)
Maintains:	receiving country	(2; 25%)
	manufacturer	(2; 25%)
	joint	(2; 25%)
	owner	(1; 12.5%)

B5./ Do you use local distributors or trading companies for selling manufacturing systems?

NA (1; 12.5%)

	Yes	No
local distributors	2 (25%)	5 (62.5%)
trading companies	2 (25%)	5 (62.5%)

three of them have representatives in the receiving country(37.5%)

B6./ Some questions about the PV cells that are used in your manufacturing system:

NA (1; 12.5%)

Cell material: Amorphous silicon (4; 50%)
Silicon - crystalline (2; 25%)
single- and polycrystal silicon cells (1; 12.5%)

Cell efficiency:	5% (@ 1000 W/m2)	(2; 25%)
	10% (13% in lab.)	(1; 12.5%)
	12-14%	(1; 12.5%)
	13-14%	(2; 25%)
	17%	(1; 12.5%)

Cost of a cell: NA (2)
$3/W
$3.5/W
$3-4/W
$4/W
$5/W

B7./ How are the manufacturing systems usually financed?

by the local Government (8; 100%)
private (3; 37.5%)
USAID (1; 12.5%)

B8./ What is the approximate cost of a manufacturing system?

NA (6; 75%)
$10 million
the smallest system is under $3 million

B9./ What foreign competition do you face?

NA (3; 37.5%)
Japan (5; 62.5%)
Germany (1; 12.5%)
 - Siemens (1)
England (1)
Europe (1)

C./ Marketing and financial issues (14 companies)

C1./ Where has your company sold these systems?

India (5; 36%)
China (3; 21%)
Thailand (2; 14%)
Africa, Algeria, Asia, Indonesia, South America, Latin America, Australia, Europe, Far East, Mexico, all over the world (1; 7%)

C2./ Where do you think the major overseas markets are?

NA (5; 36%)
developing countries (3; 21%)
everywhere (3; 21%)
Far East, Middle East, developed countries (they have money) (1; 7%)

C3./ Who were your customers typically?

NA (1; 7%)

local governments	(7; 50%)
national "	(7; 50%)
private enterprises	(7; 50%)
public bodies	(4; 29%)

C4./ Were there any involvements?

NA (2; 14%)
U.S. Government: Yes: 4 (29%)
No : 8 (57%)
Other: Yes: 5 (36%)

No : 4 (29%)
Dept. of Commerce, DOE, Red Cross, UNICEF, USAID, Peace Corps, World Health Org. (1; 7%)

C5./ Could you estimate - in the major markets - the number of units now in service and the unserved market?

Number of units in service:
- NA (12; 86%)
- under 10 MW (peak) - sold by their company (1; 7%)
- 100 systems (1; 7%)

unserved market:
- NA (10; 71%)
- 1 billion MW (1; 7%)
- everything we can make - we can sell (1; 7%)
- huge potential (1; 7%)
- 1988: $20 million, 1995 $400 million (1; 7%)

C6./ Have you ever performed feasibility studies or life-cycle cost comparisons (as part of your sales effort or for other reasons)?

NA (1; 7%)
yes, they have made (11; 79%)
no, they have not made (2; 14%)

Are these available for us?

NA (2; 14%)
yes (5; 36%)
no (7; 50%)

C7./ Do you encounter trade barriers?

NA (4; 29%)
yes (8; 57%)
no (2; 14%)

APPENDIX B.

Questionnaire sent to foreign companies, universities and organizations dealing with PV applications.

Please indicate your role in the columns by checking the appropriate lines!

	Manufac-turer	Deal-er	In-staller	Main-tainer	No role	Other role*
PV system components:						
a/ PV modules	____	____	____	____	____	____
b/ wiring	____	____	____	____	____	____
c/ connectors	____	____	____	____	____	____
d/ batteries:						
- automobile	____	____	____	____	____	____
- other:.........	____	____	____	____	____	____
e/ voltage regulator	____	____	____	____	____	____
f/ max.power tracker	____	____	____	____	____	____
g/ PV array support structure	____	____	____	____	____	____
h/ Other:...........	____	____	____	____	____	____
....	____	____	____	____	____	____
....	____	____	____	____	____	____
Loads:						
a/ water pump	____	____	____	____	____	____
b/ refrigerator	____	____	____	____	____	____
c/ lights	____	____	____	____	____	____
d/ communication equipment	____	____	____	____	____	____
e/ air conditioning	____	____	____	____	____	____
f/ Other:...........	____	____	____	____	____	____
....	____	____	____	____	____	____
....	____	____	____	____	____	____

* Please explain your role on the other side!

APPENDIX C.

Summary of Questionnaire Responses from Foreign Companies

As of January 25, 1988 there were 62 responses.

BANGLADESH

Ministry of Science and technology
They are installers and maintainers of water pumps and lights as well as PV system components.

BOTSWANA

Botswana Agricultural College
They do not have any PV systems, but there are some PV systems in the country.

Kgalagadi Resources Development Co.
They are dealers of PV modules and installers of every kind of PV system components and loads.
PV installation is their secondary business, the first one is manufacturing and distributing of solar water heating systems.

National Institute of Development and Cultural Research
They do not deal with PV, however PV systems and solar water heating systems are widely used in Botswana.

Rural Industries Promotions
They do not deal with PV.

Rural Industries Innovation Center
They are manufacturers of voltage regulators.
They design systems and they are advisors of every kind of the listed systems, plus electric fences.

BRAZIL

Heliodinamica S.A.
They deal wit a wide range of PV system components and loads.

Companhia Paranaense de Energia
They have been studying the feasibility of PV systems in Brazil, it is considered to be still very expensive, and economically impracticable.

BURUNDI

Research Center for Utilization of Alternative Energies
They do not have any role in PV, but they are interested in manufacturing, installing and maintaining of PV systems.

CAMEROON

Onarest Energy Research Unit
They are installers and maintainers of PV modules and (automobile) batteries, and manufacturers of voltage regulators, PV array support structures and electronic devices for drawing I-V curves. Their loads are lights and refrigerators.

CHILE

Universidad del Norte
(Information Centre) They do not deal with PV.

COLOMBIA

Asociacion Nacional de Industriales
They do not know any companies manufacturing PV system components in Colombia, but there is local manufacturing of batteries and fluorescent lights. There are several kinds of 12 V DC loads: radio, TV, fan, refrigerators. There are approximately 10 companies in the field of electricity generation.

Instituto de Fomento Industrial
They do not deal with PV systems. This Institute is a state development agency that works to promote establishment of new industries. The Institute acts as a financial corporation.

Ingemon Ltda.
They have workers and machinery to assemble parts and ultimate products and to produce brackets and metal parts.

COSTA RICA

Instituto Costarricense de Electricidad
They are "almost unfamiliar with the state of the art in the field of PV devices".
There are 50-60 radio links operating with PV panels. Each panel products about 2.5 Amp. at 12 V.

EGYPT

Solar Energy Laboratory

They manufacture, install and maintain PV modules and PV array support structures. They are manufacturers of water pumps (for irrigation), refrigerators, lights, communication equipment. They make equipment used in rural development. They plan to introduce PV powered equipment in Touristic Villages, far from electric grids.

ETHIOPIA

Ethiopian National Energy Commission

They are installers and maintainers of PV loads and system components, such as:

- water pumping
- refrigeration
- lights
- all the listed system components.

GRENADA

Ministry of Finance, Trade, Industry and Planning

Their Energy Unit does not deal with PV, but they are "constantly in search of more cost effective ways of providing energy"; they are interested in the Final Report.

GUATEMALA

Center for Meso American Studies on Appropriate Technology

The could build PV array support structure. They are installers and maintainers of water pumps.

HAITI

Caribsun Export-Import Inc.

They are dealers, installers and maintainers of all PV system components but max. power tracker. They manufacture PV array support structures.
Their loads are: water pumps, refrigerators and lights (dealer, installer and maintainers). They deal with PV stand alone systems. They would like to assemble PV components, but they do not have any contact or prices.

Radio Lumiere

They are installers, maintainers and end users of the following PV system components:

PV modules (Solarex, ARCO), wiring, connectors, deep cycle batteries, voltage regulators (Solarex) and PV array support structures (these are

manufactured by Radio Lumiere).
They use one kind of loads: communication equipment: FM translator.

INDIA

Electronics Corporation of India, Ltd.
"We have no plan to enter into PV line."

Hindustan Brown Boveri, Ltd.
They do not deal with PV.

Indian Space Research Organization, Satellite Center
They deal only with "the area of development of spacecraft power systems based on PV".

Kapur Solar Farms
They deal with PV system components as well as with loads.

Hermes Steel Enterprises
They are manufacturers of PV modules and PV array support structure. They are installers of every kind of PV system components and every kind of loads.

INDONESIA

Solar Energy Laboratory, Institute of Technology, Bandung
They use PV systems for education, and they test PV system performance. (They have obtained ARCO and Hollec [Netherlands] systems)

IVORY COAST

Energie Electrique de la Cote d'Ivoire
They are users of PV systems mainly in telecommunication. They develop a project to electrify a complete village. "You are welcome to help us for such a project, by ... indicating what kind of experience has been held in the U.S.A. in the last years."

JAMAICA

Scientific Research Council
They do not have any role in PV.

JORDAN

Royal Scientific Society
They install and maintain PV system components and loads and manufacture PV array support structure.

KENYA

Sunpower Products, Ltd.
They are "out of this line of business".

KIRIBATI

Ministry of Works and Energy (Energy Coordinating Committee)
They are installers and maintainers of every kind of PV system components (except PV array support structure). Their loads are: water pumps, refrigerators and lights. Sometimes they manufacture voltage regulators.

MALAWI

University of Malawi, The Polytechnic
As far as they know, there is no manufacturing of PV systems or system components in Malawi.
"PV cells are used in powering microwave transmission systems in the Post Office."
"At present the cost of cells is prohibitive", but "there could be many applications here, ..., in rural areas where there is no electrical power supply."
3 years ago there was a project (to charge batteries during daylight hours and use them in the evening for lighting), "the cost analysis revealed that the PV system was far more expensive than alternative forms of lighting".

MALAYSIA

University Malaya
They do not deal with PV.

University Sain Malaysia
They deal with PV system components and loads.

MALI

Solar Energy Laboratory of Mali
They manufacture voltage regulators for battery charger type D and C, and some PV array support structure.
They are installers and maintainers of every kind of (whole) systems.

MAURITANIA

Societe Nationale pour le Developpement Rural
They are installers and maintainers of water pumping

systems. They are interested in our final report very much, because they want to install irrigation, village power and grain drying systems.

NEPAL

Development and Consulting Services

They deal with PV system components (no loads). They are interested in PV systems, but they "find that it is still 3 to 5 times as expensive as micro hydro". "PV is used in remote areas privately or for hospitals and communication".

Research Center for Applied Science and Technology

They are installers and maintainers of water pumping and lighting systems. They test these systems and PV arrays as well.

Swiss Association for Technical Assistance

They are installers and maintainers of PV modules, wiring, batteries, and installers of voltage regulators. They are installers and maintainers of lighting systems. They are projectors in two fields:

- Forestry Advisor: they purchased and now maintain a portable equipment for battery recharging. These batteries are used in village level education programmes.
- Private: house lighting systems (12 V), they purchase, install and maintain these systems.

NEW CALEDONIA

South Pacific Commission

- This is a regional advisory and technical assistance agency which provides consultant services to 22 member states. In the PV field they do research and analysis of energy needs, they make full-scale models of PV systems (lighting, water pumping and refrigeration). Their recent PV program is financed by the European Economic Community.

NIGERIA

University of Lagos

They are installers and maintainers of PV modules, wiring and voltage regulators. They are installers and maintainers of the following loads: water pumps and communication equipment.

PANAMA

Hydraulic Resources and Electrification Institute

They are installers of five vaccine refrigeration systems and one radio-communication equipment. They are working on electrification of small rural villages. They have a (near) future program to install 70 vaccine refrigeration systems.

PAPUA NEW GUINEA

Lik Lik Buk Information Center

They are involved in R&D of PV applications at village level.

(Association of Technologists) Department of Forests

They "do not have any experience and knowledge of PV systems in this country", but they are interested in the final report.

PHILIPPINES

San Miguel Corp.

They are users and maintainers of PV systems.

SAINT LUCIA

Ministry of Finance and Planning (Central Planning Unit)

There is only one PV system installed in Saint Lucia (no data about it), and there are two automobile battery manufacturers (installers) in Saint Lucia.

SAMOA

Prime Minister's Department, Western Samoa Energy Committee

They are installers and maintainers of every PV system component, and every kind of loads. All the PV equipment and associated materials for the whole country are imported from overseas. With regards to the PV systems they acted as consultant by providing the technical expertise through one of their engineers. Two other government departments in Health and Post Office also install and maintain their own PV systems.

SAUDI ARABIA

King Saud University (U. of Riyadh)

They use Solec ARCO PV modules and Delco 2000 batteries. They are installers and maintainers of refrigeration and air conditioning (water cooled too) systems. They make all design work, wiring and connections.

King Abdul Aziz University

They design PV systems for telecommunication systems at airports and other facilities. They use Saudi made PV modules. They are designers of PV modules and communication equipments.

SIERRA LEONE

Njala University College

They are manufacturers of PV array support structures, installers of (automobile) batteries and support structures, and maintainers of wiring, connectors, batteries and voltage regulators. They have no max. power trackers. They are maintainers of the following loads: water pumps, refrigerators and lights.

SOUTH AFRICA

P. Andrag & Sons (Pty) Ltd.

Due to the high costs, they do not deal with PV systems, but they are interested in receiving our final report and any further help.

Southern Cross Windmill & Engine Co.

They do not deal with PV.

Stewarts & Lloyds Trading

They are dealers of PV system components and loads (water pump and lights).

SRI LANKA

International Executive Services Corps

They are interested in solar power for lighting and refrigeration. They worked on the refrigeration project with the help of a Dutch group. There is one small firm in Sri Lanka (no name mentioned) which produces a small solar panel feeding a motor cycle battery, and another group that is just about starting to manufacture solar panels (no name mentioned).
There are some hotels using solar panels from Australia for hot water systems.
They would like to develop solar powered water pumping systems and motors.

TANZANIA

(Arusha) CAMARTEC (Center for Agricultural Mechanization and Rural Technology

They are manufacturers and installers of water pumping systems. They just started the research on solar energy and application. Manufacturing of PV system components is a future possibility.

University of Dar es Salaam

They are installers and maintainers of communication equipment (on the top of Mountain Kilimanjaro).

THAILAND

Khon Kaen University, Faculty of Engineering

They offer courses and conduct research and development on PV systems. They design and develop max. power tracking unit and voltage regulators.

National Energy Administration

They are installers of all PV system components except max. power tracker, (the batteries are of sealed type) and installers of water pumps, lights, refrigerators and communication equipments.

Thailand Institute of Scientific and Technological Research

They are working presently on location selection, materials used in solar equipment and on corrosion problems.

TRINIDAD

Climate Control

Air conditioning and refrigeration.

TUNISIA

Ecole National d'Ingenieurs de Tunis

They are installers and maintainers of every kind of PV system components. They manufacture wiring, connectors, automobile batteries and PV array support structures. They are doing a scientific research on PV cells using thin film semiconductors. Their loads are: water pumps, refrigerators, lamps, communication equipment and anodic protection.

APPENDIX D

Listing of VP-EXPERT Program

```
! Program to choose least cost components and size PV water
! pumping system to minimize total initial cost.
! Current version limited to jack or dc-submersible pumps, LOLP=1%,
!    Kt = .5, horizontal array.
Ask people: "Input number of people to be served by pump:";
Ask head: "Input hydraulic head (meters):";

ACTIONS
PRINTON   Display "Optimal PV System Component Selection and Sizing"
prod1 = 200
prod2 = 800
prod3 = 2000

Find pump
Display "For a hydraulic head of {head} m and {people} people to be served,"
Display "the optimal pump type is {pump}.";

Rule 1
If flow > 0
then prod = 50;


Rule 2
If head > 30 and
flow < 13
then pump = volumetric;

Rule 3
If prod > (head * flow)
then pump = handpump;

Rule 4
If head < 6 and flow > 25
then pump = centrifugal;

Rule 5
If prod2 > (head * flow) and prod < (head * flow)
then pump = dc_submersible;

Rule 6
If prod3 > (head * flow) and prod2 < (head * flow)
then pump = dc_turb_or_ac_subm;
Rule 0
If people > 0 then flow = ((people)*0.045); ! assumption:  45 l/person/day

Rule 8
If head > 0
and flow > 0
then load = ((head) * (flow)*9.8/3.6/eff);
 !load in Whr/day, with efficiency of pump and plumbing accounted for.

Ask insol: "Horizontal average worst month insolation (kWh/day):";


Rule 7
If pump = centrifugal
then eff = .2  !20% efficiency for centrifugal pump system
else eff = .4; !40% efficiency for the other pump systems



Actions
Find eff
find load
```

```
format load,5.0

Display "The pump load is (load) Wh/day."
find insol
!The following parameters are for tilt of (latitude - 10 degrees)
![i.e., essentially horizontal for Nigeria] and for a clearness
!index of 0.5 (again the approximate value for northern Nigeria)
!and are from Klein and Beckman (1988, Solar Energy) for a loss
!of load probability (LOLP) of 1%:

slr[1] = 1.07
B[1] = 5
slr[2] = 1.12
B[2] = 4
slr[3] = 1.28
B[3] = 3
slr[4] = 1.85
B[4] = 2
!slr is the solar to load ratio of the array
!B is the ratio of storage to daily load
;
!choose

ACTIONS
!program now to extract cost info from worksheet ("b:costs.wks")
!and to determine least cost system.

coststl = 0
costl=0
costst = 0
cost = 0
WKS a,named=all,b:costs
  l_array_l=(a[26])
  l_cell_l=(a[27])
  l_fence_l=(a[28])
  l_module_l=(a[29])
  l_mpt_l=(a[30])
  l_pump_jac_l=(a[31])
  l_pump_sub_l=(a[32])
  l_storage_l=(a[33])

  i_array_l=(a[9])
  i_cell_l=(a[10])
  i_fence_l=(a[11])
  i_module_l=(a[12])
  i_mpt_l=(a[13])
  i_pump_jac_l=(a[14])
  i_pump_sub_l=(a[15])
  i_storage_l=(a[16])

  import_array=(a[1])
  import_cell=(a[2])
  import_fence=(a[3])
  import_module=(a[4])
  import_m_p_trac=(a[5])
  import_pump_jac=(a[6])
  import_pump_sub=(a[7])
  import_storage=(a[8])

  local_array=(a[17])
  local_cell=(a[18])
  local_fence=(a[19])
  local_module=(a[20])
  local_m_p_trac=(a[21])
  local_pump_jac=(a[22])
  local_pump_sub=(a[23])
  local_storage=(a[24])

  local_well=(a[25]);
```

```
Plural:  system;
Rule 19
If import_cell > 0
then system = imported_wafers;

RULE 20
If import_cell < (local_cell)
then system = import_cell
cost = ((cost) + (import_cell))
costl = ((costl) + (i_cell_l))
else cost = ((cost) + (local_cell))
system = local_cell
costl = ((costl) + (l_cell_l));
RULE 21
If import_array < (local_array)
then system = import_array
cost = ((cost) + (import_array))
costl = ((costl) + (i_array_l))
else cost = ((cost) + (local_array))
system = local_array
costl = ((costl) + (l_array_l))
;
RULE 22
If import_fence < (local_fence)
then system = import_fence
cost = ((cost) + (import_fence))

costl = ((costl) + (i_fence_l))
 else cost = ((cost) + (local_fence))
system = local_fence
costl = ((costl) + (l_fence_l))
;
RULE 23
If import_module < (local_module) and import_cell < (local_cell)
then system = import_module
cost = ((cost) + (import_module))
costl = ((costl) + (i_module_l))
else cost = ((cost) + (local_module))
costl = ((costl) + (l_module_l))
system = local_module;
RULE 24
If import_m_p_trac < (local_m_p_trac)
then system = import_max_power_tracker
cost = ((cost) + (import_m_p_trac))
costl = ((costl) + (i_mpt_l))
else cost = ((cost) + (local_m_p_trac))
costl = ((costl) + (l_mpt_l))
system = local_max_power_tracker;
RULE 25
If import_storage < (local_storage)
then system = import_storage
cost = ((cost) + (import_storage))
coststl = ((coststl) + (i_storage_l))
else costst = ((costst) + (local_storage))
coststl = ((coststl) + (l_storage_l))
system = local_storage;
RULE 26
If import_pump_jac < (local_pump_jac) and pump = volumetric
then system = import_jack_pump
cost = ((cost) + (import_pump_jac))
costl = ((costl) + (i_pump_jac_l))
;


RULE 27
If import_pump_jac >= (local_pump_jac) and pump = volumetric
```

```
then cost = ((cost) + (local_pump_jac))
costl = ((costl) + (l_pump_jac_l))
system = local_jack_pump;

RULE 28
If import_pump_sub < (local_pump_sub) and pump = dc_submersible
then system = import_submersible_pump
costl = ((costl) + (i_pump-sub_l))
cost = ((cost) + (import_pump_sub));


RULE 29
If import_pump_sub >= (local_pump_sub) and pump = dc_submersible
then cost = ((cost) + (local_pump_sub))
costl = ((costl) + (l_pump_sub_l))
system = local_submersible_pump;



ACTIONS
find system
format cost,3.2
format costl,3.2
format costst,4.2
format coststl,4.2
Display "
Components include:
{system}
"
Display "System array-related cost estimate (US $/peak watt):  {cost},"
Display "of which ${costl}/Wp remains in the local country."
Display "Storage-related cost estimate (US $/cubic meter water):  {costst}"
Display "of which ${coststl}/m3 remains in the local country.";

ACTIONS


slope = (0-(cost)*(load)/(insol)/(flow)/(costst))
x = 1
WHILEKNOWN stop
reset stop
x = ((x) + 1)
xm = ((x) - 1)
find stop
slope[xm] = (((b[x]) - (b[xm]))/((slr[x])-(slr[xm])))
END
find slropt
find Bopt



;
Rule 10
if x < 4
then stop = no;

Rule 11
If slope <= (slope[1])
then slropt = (slr[1])
bopt = (b[1]);

Rule 12
If slope > (slope[1]) and slope <= (slope[2])
then slropt = (slr[2])
bopt = (b[2]);
```

```
Rule 13
If slope > (slope[2]) and slope <= (slope[3])
then slropt = (slr[3])
bopt = (b[3]);

Rule 14
If slope > (slope[3])
then slropt = (slr[4])
bopt = (b[4]);
ACTIONS
! for program development:  display "optimal slr = {slropt}"
! for program development:  display "optimal B = {bopt}"
arraysize = ((slropt)*(load)/(insol))  ! in Wp
storsize = ((bopt)*(flow))! in cubic meters
Display "
    For a horizontal insolation of {insol} kWh/m2/day:"

format arraysize, 5.0     format storsize, 4.0
display "Optimal array size:  {arraysize} Wp"
display "Optimal water storage size:  {storsize} cubic meters"
arraycost = ((arraysize)*(cost))
storcost = ((storsize)*(costst))
localcost = ((costl)*(arraysize))
locstor = ((coststl)*(storsize))
format arraycost,5.2
format storcost,5.2
format localcost,5.2
format locstor,5.2
display "Array-related cost:  ${arraycost}, of which ${localcost} remains locally."
display "Storage cost:  ${storcost}, of which ${locstor} remains locally."
wellcost = ((local_well)*(head))
format wellcost,5.2
display "Well cost:  ${wellcost}"
totcost = ((arraycost) + (storcost) + (wellcost))
format totcost,5.2
Display "Total system cost:  ${totcost}"
;
```