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INTRODUCTION

In a recent paper (ref. 1) we examined the total domestic fossil fuel, uranium and hydro-energy reserves of all developing countries with a population greater than one million, and classified these countries according to their ability to meet present and projected energy demand for 1990 from these domestic reserves. Two groups of countries were identified which offer attractive opportunities for use of solar energy (Groups A and B, below).

Group A

Countries which are unable to provide 10 percent of their present energy demand from domestic reserves of fossil fuels, uranium and hydro-power:

Benin	Lebanon
Burundi	Malawi
Cuba	Singapore
Dominican Republic	Yemen, Arab Republic
Haiti	Yemen, People's Democratic Republic
Jamaica	

Group B

Countries able to provide 10 percent of their present energy consumption from domestic reserves of fossil fuels, uranium and hydro-power, but which are unlikely to meet 10 percent of their estimated 1990 energy demand domestically from the same source:

El Salvador	Somalia
Jordan	Sri Lanka
Morocco	Thailand
Rwanda	Uruguay

This paper discusses technical and market aspects of solar energy in these two groups of developing countries. It is difficult to present a comprehensive analysis in a short report such as this, and the discussion consequently has been limited to a presentation of the potential for solar photovoltaic energy usage in the countries noted above.

It is our opinion that these two groups of countries represent important markets for the utilization of thermal and photovoltaic solar energy. We do not wish to imply that other countries do not offer attractive opportunities for the use of solar energy. On the contrary, in terms of total energy demand more populous countries such as India, Pakistan and Brazil are likely to represent a larger potential market than the countries mentioned in Groups A and B. However, in terms of need and potential social and economic impact, the countries listed in the two groups would rank very high in solar market potential.

Profile of the Countries

Summarized in tables 1 and 2 are some of the data that can be used to indicate a need for solar energy systems in the countries discussed herein. Most of the countries have a negative balance of trade resulting in part from the necessity to import energy supplies. Per capita income and per capita consumption of electricity are low in comparison to developed nations. However, each nation in the two groups has a very abundant supply of sunshine as shown in table 2.

Methodology

The procedure used to develop solar energy cost estimates consisted first of estimating the average daily solar radiation at the locations specified. The primary source of this information was the World Survey of Climatalogy (ref. 2). When the solar radiation (insolation) data was not available from the above, reference 3 was used to provide an estimate. Insolation is measured in the unit langleys per day (one langley equals one calorie per square centimeter). After obtaining the solar insolation estimate, current prices of photovoltaic systems were used to estimate the range of energy costs for solar photovoltaic installations. Included in the estimate were assumptions of 10 year lifetimes for the systems and 8 percent annual interest rates on capital. Details of the methodology are presented in the Appendix.

DISCUSSION

Cost estimates for photovoltaic energy are shown in table 2 for a location within each country in Groups A and B. The cost estimates are based on 1977 prices in the United States. The prices for solar photovoltaic systems were approximately $1350 per square meter in 1977. There are variations in price and performance, and so these estimates represent average system prices.

Solar electricity has been developed to a point where it has begun to compete in the marketplace as a reliable source of energy. Photovoltaic technology is a semiconductor-based technology that has benefited from the rapid development in semiconductors over the past several years. As a result of the technology improvements and increased production, prices paid for U. S. Government purchases have declined by 40 percent in the last 2 years. As photovoltaic technology is improved and demand increases, system prices will continue to decrease substantially over the next 5 to 10 years.

The costs per kilowatt hour estimates in table 2 range from about $1.60 to $2.20 for solar electricity. For comparison, electrical energy in the United States typically costs from 3 to 10 cents per kilowatt hour. However, in less developed areas of the world where it is necessary to use autogeneration (diesel/gasoline powered generators), electricity may cost up to 70 cents per kilowatt hour for public supplies with low utilization factors (ref. 5). For very small power demands, autogeneration may be as much as several dollars per kilowatt hour because of logistics and minimum size limitations of generating equipment.

A common problem experienced in rural electrification programs in developing countries is that central power systems require relatively long periods of time to reach reasonable load factors. The design philosophies of these systems incorporate savings due to economy of scale on the production side of the market. However, the consumption or demand cannot usually be developed rapidly. The cultural infrastructure of a rural area is changed slowly. People must acquire the devices that use energy. Markets must be established and so it may be 5 to 10 years before a central power facility reaches what is considered a respectable load level. One of the consequences of the gradual increase in the use of a central power facility in a rural area is that the unit energy costs are high initially and decline over the life of the power plant until the plant is producing at capacity. Data from 1971 published in reference 5 provide an example of declining costs in relation to demand for central power. In the first year of operation, energy costs may average 30 to 35 cents (in 1971 U. S. dollars) per kilowatt hour. By the seventh year of operation, costs may decline to 15 cents per kilowatt hour (also in 1971 U. S. dollars). It should be kept in mind that, because of the substantial rise in fuel costs since 1973, the costs will be much higher for a system coming into use now. Fossil-fueled generation systems are approaching a point where they may not be economically attractive in comparison to the cost of solar energy for rural electrification.

Electricity generated from photovoltaic systems is expensive on a kWH cost basis. However, the costs could already be lower than autogeneration in some areas. This is frequently the case in rural areas of the developing countries, where only small quantities of electricity can be afforded for "essential" purposes, such as lighting, water pumps, communications, and sometimes for the introduction of cottage industries.

For example, a comparison between an autogeneration system and a photovoltaic system can be made using a rural area of Haiti. The annual per capita consumption of electricity is 32 kWH and the per capita income is $158 (table 1). Solar insolation is about 521 langleys per day on the average. There may not be a need for thermal energy but electricity could be usef for lighting, water pumping or even educational television. A family of six people may have an annual income of $950. According to reference 5, a reasonable expenditure for electricity and appliances such as lights, and a television would be 6 percent of family income or $58 per year in this case. A photovoltaic system, 20 watts of fluorescent lighting and a television can be purchased for about $450 in the U.S. in reasonable quantities of, say 100 units. At 8 percent interest over a 10 year life, the annual payment would be about $67 per year or marginally affordable in this case. If interest costs were subsidized, this system could easily be afforded.

A gasoline powered motor generator set, television and fluorescent lighting could also be purchased for about $450 in quantities of about 100 units. The power output from the motor generator would be about 20 times more than needed, would probably last 1 year and require maintenance, and cost approximately 1 dollar per day for gasoline. The photovoltaic system will require washing of the collector occasionally and periodic inspection. The use of either system would bring the family up to about 15 percent of the per capita electricity consumption for Haiti. Analysis would show comparable results for the other countries. An advantage of the photovoltaic system implied here is that the power system is modular and can be increased in size as demand increases and funds become available.

CONCLUSION

A major advantage of photovoltaic systems is modularity. One can start with a system of any size and add to the system as the demand builds up and funds become available. Another advantage is the trouble-free operation of systems which require little maintenance. This is an important consideration for remote areas where trained manpower is seldom available. In spite of these advantages, the use of photovoltaic electricity on a wide scale is restricted because of its initial system cost. Being competitive with fossil-fuel systems is not enough in itself since many rural areas cannot afford either system when the average per capita income is only of the order of $100 to $400 per year. The cost of photovoltaic systems will have to decrease in order to become an economically viable source of electrical energy for developing nations.

Fortunately, the cost of photovoltaic systems has been decreasing rapidly. The U.S. Department of Energy has set a target of 50 cents per peak watt for the photovoltaic collectors by 1985, about 5 percent of what it costs today. Even at the reduced prices, it will cost millions of dollars to provide some electrical energy to the rural areas of just the countries noted herein. Most of these countries are already running a deficit in their balance of payments (table 1) and are not is position to import more from the industrialized nations which are presently producing the solar cells. International agencies involved in development assistance, such as The World Bank, the Asian Development Bank, and the Agency for International Development will have to assist, as they have in the past.

The introduction of solar power on a broad scale into the rural areas of the developing countries could have significant social and economic impact. However, it will require time to establish a base for manufacture, assembly and distribution channels required to market and service solar energy systems in developing nations. It would consequently be very desirable to test solar electric systems in selected villages around the world, representing a variety of cultures, at an early date. Such testing would allow an evaluation of the social, economic and environmental impact of rural power systems, and minimize potentially undesirable effects, before the technology is introduced on a broad scale.

APPENDIX

Procedure for Estimating Energy Costs

Present installed system costs for solar photovoltaic conversion systems are about $1350 per square meter (ref. 4).

Assuming a 10 year system life and using 8 percent annual interest, equivalent annual costs may be determined for 1 square meter of collector. Solar radiation is usually reported in the unit langleys per day. One langley is equal to 1 calorie per square centimeter. Transforming this unit into kilowatt hours per square meter and allowing for the photovoltaic system conversion efficiencies allows the calculation of energy costs in dollars per kilowatt hour, based upon an estimation of the daily solar insolation incident upon a geographic area. Details of the cost estimation procedure are given below.

Solar Photovoltaic System Energy Cost Estimate

Solar insolation of 1 langley per day at an average conversion efficiency of 5 to 6 percent delivers 0.212 to 0.254 kWH per square meter of photovoltaic collector per day. Using 8 percent annual interest, the capital recovery factor for 10 years is 0.149. Installed systems presently cost about $1350 per square meter, and the equivalent annual system cost per square meter is about $200. Thus, insolation of 1 langley per day yields an annual energy cost estimate of $943 to $787 per kWH. Dividing these estimates by the average daily solar insolation yields an energy cost range for a particular geographic region. The estimates for the nations included in this report typically are around $2 per kilowatt hour. The estimates are intended only for the purpose of defining the range of costs for the countries discussed in this report. Actual values will depend on many factors not considered explicitly in the estimation procedure.

An important consideration for photovoltaic systems is the rapidly decreasing price of these systems. Electrical energy from photovoltaic systems costing about $2 per kilowatt hour presently is expected to cost much less by the 1983-85 time period. A more reasonable estimate by that time would be a range from about 25 to 50 cents per kilowatt hour in 1977 U.S. dollars.

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TABLE 1. - SELECTED DATA FOR COUNTRIES CONSIDERED PRIME CANDIDATES FOR DEVELOPMENT OF SOLAR ENERGY SYSTEMS.

ALL DATA ARE FOR 1974, UNLESS OTHERWISE INDICATED.

Country	Population (millions) (ref. 6)	Population density (no. of persons per square kilometer) from refs. 6 and 8	Energy consumption per capita (kilograms of coal equivalent per year) (ref. 8)	Electric energy consumption per capita (kWh/yr) (ref. 8)	Balance of payments (last available year) (in millions of U.S. dollars) (ref. 9)	Per capita income (in U.S. dollars) (ref. 8)
Benin	3.0	27	42	17	-32.1 ('74)	76
Burundi	3.7	132	13	6	N/A	60
Cuba	9.1	79	1178	1433	N/A	N/A
Dominican Repub.	4.6	94	433	329	-96.5 ('75)	480
El Salvador	3.9	182	242	247	-8.4 ('76)	382
Haiti	4.5	162	31	32	-56.6 ('75)	158
Jamaica	2.0	182	1439	1109	-302.7 ('76)	1273
Jordan	2.6	27	388	119	-307.7 ('75)	339
Lebanon	3.1	298	1073	705	N/A	589
Malawi	5.0	42	56	46	-49.8 ('74)	128
Morocco	16.3	36	257	165	-1044.0 ('75)	440
Rwanda	4.1	156	13	32	+13.6 ('76)	54
Singapore	2.2	3786	2060	1756	-709.0 ('75)	870
Somalia	3.1	5	40	14	-102.2 ('75)	87
Sri Lanka	13.4	204	140	74	-188.9 ('75)	223
Thailand	40.8	79	300	179	-687.0 ('75)	318
Uruguay	2.8	158	900	819	-215.9 ('75)	1091
Yemen, Arab Rep.	6.4	33	30	4	+296.5 ('76)	126
Yemen, People's Demo. Rep.	1.6	6	360	109	-99.5 ('74)	92

TABLE 2. - SELECTED METEOROLOGICAL AND COST DATA FOR COUNTRIES IN GROUPS A AND B

Country	Location	Temperature extremes (°C) (refs. 2, 10, 11)	Solar insolation (ly/day) (refs. 2 and 3)	Estimated solar energy cost (U.S. $/kWH)	Comparable U.S. location for sunshine (ref. 3)
Benin	Nattingou	13 to 45	546	1.7	El Paso, TX
Burundi	Kisozi	7 to 25	453	2.1	Tampa, FL
Cuba	Camaguey	10 to 35	502	1.9	Las Vegas, NV
Dominican Repub.	Santo Domingo	15 to 33	519	1.8	Tucson, AZ
El Salvador	San Salvador	16 to 32	463	2.0	Los Angeles, CA
Haiti	Port au Prince	24 to 28	521	1.8	Phoenix, AZ
Jamaica	Kingston	14 to 36	488	1.9	Pearl Harbor, HI
Jordan	Amman	11 to 24 ('76 actuals)	488	1.9	Pearl Harbor, HI
Lebanon	Bierut	2 to 32	471	2.0	Pearl Harbor, HI
Malawi	Mzimba	1 to 33	504	1.9	Las Vegas, NV
Morocco	Marrakesh	-1 to 45	445	2.1	Miami, FL
Rwanda	Rubona	11 to 28	466	2.0	Los Angeles, CA
Singapore	Singapore a/p	25 to 30 ('76 actuals)	413	2.2	Charleston, SC
Samolia	Mogadiscio	16 to 40	580	1.6	China Lake, CA
Sri Lanka	Colombo	26 to 28 ('76 means)	498	1.9	Las Vegas, NV
Thailand	Bangkok	27 to 30 ('76 actuals)	435	2.2	Miami, FL
Uruguay	Montevideo	-5 to 43	421	2.2	Lexington, KY
Yemen, Arab Rep.	San'a	-8 to 30	513	1.8	Honolulu, HI
Yemen, People's Democratic Rep.	Aden	0 to 38	513	1.8	Honolulu, HI