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SOLAR ENERGY FOR RURAL DEVELOPMENT IN THE THIRD WORLD

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ABSTRACT

Addae, Kwasi David. Solar Energy for Rural Development in the Third World

One of the pre-eminent assumptions held by many international and other economists concerned with economic development in the Third World since W. W. Bostow's seminal work, "The Stages of Economic Growth," has been that less developed countries (LDCs) must pass through various phases of industrial growth before they are able to achieve increased level of productivity and higher standards of living. The argument followed that as LDCs developed from primary agricultural and mining related economic base towards secondary and tertiary processing, manufacturing and service related industries, necessary infrastructural and other supporting industrial activities would be disturbed by some sort of forward and backward linkages.

Although the above assumption, as outlined in its most basic and somewhat oversimplified form, has had a tremendous influence among Third World policy makers, its validity has begun to be questioned in recent years. As the problems associated with soaring fuel costs, (high unemployment and inflation, and environmental mismanagement, to name just a few of the pit falls associated with heavy industrial development in fossil-fuel-poor Third World countries) continue to retard developing economies, the need to critically examine current urban and industrial growth policies seems appropriate.

The first and second chapters of this thesis examine some of

the problems that have emerged a consequence of capital and fossil fuel intensive growth in the various regions of the Third World. The third chapter attempts to provide the reader with sufficient theoretical background in order to adequately assess some of the economic implications associated with developing capital intensive development policies.

Chapter four examines the form or forms that solar energy could be adopted in the rural Third World. Attention is focused on the various uses of solar energy. The last chapters examine the potential solar energy utilization for agricultural crop drying in the rural areas, using a framework of cost-benefit analysis.

CHAPTER I

INTRODUCTION

Development, economic growth and energy consumption are closely related. However, the relationship between the type of economic growth and the way in which energy is used is rarely considered.

Developing countries[1] have chosen, at least until now, to follow the well-beaten development paths pioneered by the industrial world. Unfortunately, many Third World Nations are now realizing that the capital--and exhaustible fuel-intensive technologies have not greatly contributed to the economic development of small, rural communities. Centralized energy systems imbody a conception of science and application of technology that are impractical and unrelated to the development needs of remote Third World villages.

One of the major differences between the high yielding technologies employed by modern agri-business and the low yielding traditional methods used in developing countries is much higher energy consumed per hectare in agri-business. In order to increase Third World agricultural productivity, labor using rural oriented development strategies that use indigeneous located resources should be investigated. The development

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[1]The term "Third World" and "Developing Countries" will be used interchangeably to refer to fossil-fuel and capital-poor LDCs.

of new or existing (ie. traditional) "renewable"[2] sources of energy and conversion technologies seems to hold great promise in dealing with many Third World problems. Solar[3] energy, wind, geothermal, hydro-electric and biofuel sources seem to represent the most likely renewable energy resource candidate that can be developed in a cost competitive and welfare maximizing manner if appropriate planning objectives are pursued. This has become an urgent need, since, in the long run, rural Third World villagers cannot afford to pay the price for increasingly expensive conventional fuels and related technologies.

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[2]For the time being, a renewable source of energy can be simply defined as a type of energy that can be converted into humanly usable form without permanently affecting its future availability after it has been consumed.

[3]UN conference on New and Renewable Sources of Energy in Nairobi - August 10-21, 1981, Ghanaian Times August 25, 1981.

LITERATURE REVIEW AND OBJECTIVES

One of the pre-eminent assumptions held by many international and other economists concerned with economic development in the Third World since W. W. Bostow's seminal work, "The Stages of Economic Growth," has been that less developed countries (LDCs) must pass through various phases of industrial growth before they are able to achieve increased level of productivity and higher standards of living. The agricultural and mining related economic base towards secondary and tertiary processing, manufacturing and service related industries, necessary infrastructural and other supporting industrial activities would be disturbed by some sort of forward and backward linkages.

Although the above assumption, as outlined in its most basic and somewhat oversimplified form, has had a tremendous influence among Third World policy makers, its validity has begun to be questioned in recent years. As the problems associated with soaring fuel costs, (high unemployment and inflation, and environmental mismanagement, to name just a few of the pit falls associated with heavy industrial development in fossil-fuel-poor Third World countries) continue to retard developing economies, the need to critically examine current urban and industrial growth policies seem appropriate.

As indicated, capital and exhaustible fuel-intensive technologies have not greatly contributed to the economic development of small, rural communities. Centralized energy systems embody a conception of science and application of science and technology that are impractical and unre-

lated to the real development needs of remote Third World villages. For example, nuclear energy hardly represents an appropriate application of science and technology for use in rural villages. Both fusion and fission energy require highly capital and technical skill-intensive technologies.

Conventional fission relies on exhaustible fuel sources, produce environmentally deleterious externalities (ie. radioactive wastes) and can only be used to generate electricity. Although geothermal, tidal and ocean thermal energy conversion (OTEC) facilities hold great promise for diversifying the industrialized world's energy base, such systems are highly capital and technically intensive, making them less appealing candidates in rural, Third World development strategies. The scale and complexity of such technologies not only make them less accessible to relatively poor and politically weak, rural inhabitants but also increase the likelihood and impact of mechanical malfunctions, human error and deliberate sabotage, which represent potentially burdensome social costs when developing large scale facilities.

Specifically, the following energy needs must be reorganized by any Third World development strategy in order to increase agricultural productivity and eventually achieve a functional primary infrastructure:

(a) In the rural sector, energy is required to pump water for irrigation, drainage, drying, preserving and processing agricultural products. To increase agricultural productivity, energy is needed to power machinery that can work the land as well as using more efficient seed bedding processes.

(b) To increase soil fertility, more efficient and environmentally sound land management techniques need to be adopted (eg. using

exhaustible fuel saving "organic" fertilizers as a source of heat).

(c) Small, rural industries need power for such diverse primary processes as grain threshing and milling fodder crushing, vegetable oil extraction and timber sawing.

(d) In the household and public service sectors, energy is needed for transportation, communications, lighting, refrigeration, space and water heating, cooking, distillation and sterilization which represent requirements that upgrade public welfare and the living standards of rural Third World inhabitants.

Many of the preceeding energy needs can be satisfied using small scale, "renewable" based technologies. However, the tasks for which energy is needed may vary greatly among developing countries. In some of the arid countries, for example, the most pressing need may be the use of pumps to bring water from a deep water table to the parched surface.

In areas with more abundant water supplies, cooking fuel may be in desperate short supply and any development strategy would need to reorganize such varying and diverse requirements on regional basis.

Two questions seem to be relevant, one is in what form or forms could the solar energy be adopted in the rural Third World? Secondly, how economical is it? The first question relates to system design and second on cost effectiveness. These two questions need further studies since the world crude oil prices still stay high and show no real signs in drastically declining and as the electricity price maintains an upward trend. It is foreseeable there will be a growing interest in solar energy and further advancement in solar technology and application.

Objectives

This thesis has the following objectives:

1. Critical examination of the need and possibilities of developing solar energy technologies in the Third World.
2. In what form or forms that the solar energy could be adopted in the rural Third World? Attention is focused on the various specific uses of solar energy.
3. Potential solar energy utilization for agricultural crop drying in Senegal using cost benefit analysis.

CHAPTER II

PROBLEMS OF THE THIRD-WORLD ECONOMICS

The Effect of Rising Exhaustible Fuel Costs

The repercussions of continually rising prices for fossil fuels (eg. petroleum and coal) and natural gas (eg. butane, propane and geo-pressurized methane) has forced many developing countries to face the prospect of attempting to project themselves through various stages of economic development without the benefits of low cost exhaustible fuels (ie. fossil fuels and natural gas). Throughout the industrial revolution and succeeding drive to industrial maturity rapidly declining fuel costs propelled the present day advanced countries through various stages of economic development at a phenomenal rate.

Today however, many Third World nations are still experiencing the economic disruptions or "supply shocks" that emanated from the Arab Oil Embargo. As a result, the subsequent increase in petroleum prices has created yet another obstacle inhibiting economic growth and development in most of the Third World. Furthermore, due to the escalation of costs resulting from the exhaustion of more accessible non-renewable reserves (ie. fossil fuels and natural gas), developing countries with limited financial and energy resources are being left further behind in terms of economic development and find themselves more vulnerable to the social and political unrest in current world order.

To illustrate the magnitude of this problem, in 1977 the United

Nations (UN) estimated that of the 74.7 trillion metric tons of proven global petroleum reserves, only about five percent were located in non-OPEC developing countries. As for natural gas, the developing countries accounted for about seven percent of the proven 633 trillion cubic meters of reserves, with coal accounting for about ten percent of the known 1,076 trillion metric tons in reserves (UN, 1976).

Latin American countries, where exhaustible fuel consumption has highly concentrated on industrialized urban sectors, are more dependent on oil than almost any other developing region in the world, based on Inter-American Development Bank estimates. In 1975, oil supplied 70 percent of South America's total energy requirements; and in some South American countries it accounted for more than 90 percent (UN, 1980). For example, in Brazil, increases in petroleum prices have contributed to the sudden doubling of the value of imports, plus a worsening in the overall balance of payments (UN, 1980). Brazil, which is almost completely dependent on foreign sources for its petroleum supplies, spends about ten million dollars per day on petroleum imports alone which represents about fifteen percent of Brazil's imports bill.

In India, the shortage of electrical power, due to the high costs of exhaustible fuel, is viewed as a major constraint on the growth of both industry and agriculture and is held responsible for many of the short falls in government planning objectives (Renelle, 1976). The Indian government has estimated the short fall of one million tons of fossil fuel imports would result in a loss of about eight million tons of grain annually (Revelle, 1976). In addition, the shortage of irrigation fuel reduced the wheat harvest in Northern India by a million tons, which could have fed six million Indians for a year. India currently meets

two-thirds of its consumption of oil from imports, after the OPEC inspired rural and urban areas in order to control the demand for petroleum (Ayres, 1978).

Because of the increased cost of nitrogenous fertilizers, a natural gas by-product, the 32 developing countries singled out by the United Nations (UN) as "most seriously affected" by the increased cost of exhaustible fuels (with most of them having among the lowest income per capita in the world), suffered a shortfall of 337,000 tons of fertilizer and a resultant grain loss of about 7.7 million tons (UN, 1980).

The high costs of exhaustible fuel have greatly contributed to the economic burdens of the Third World, especially in less accessible rural areas, where, due to the difficulty of transporting such fuel to isolated villages, the costs of exhaustible fuels are even higher. High exhaustible fuel costs have placed not only a difficult burden on exhaustible duel dependent, urban-based industries, but has also exacerbated the generally low level of agricultural productivity and standard of living in rural sectors of most developing countries.

The increase in exhaustible fuel costs has directly affected overall and current account trade balances - (Table 1 and 2).

TABLE 1

OVERALL BALANCE OF TRADE
(in millions of dollars)

Area	1971	1974	1975	1976
WORLD				
Developing total	-3483[4]	52,442	10,883	30,147
Petroleum exporting	9,927	85,705	55,316	61,147
Non-oil developing	13,411	33,264	45,697	31,699
WESTERN HEMISPHERE				
Developing total	3,585	6,614	13,697	10,497
Petroleum exporting	87	6,545	2,441	918
Non-oil developing	3,671	13,160	16,138	11,415
AFRICA				
Developing total	550	10,266	3,595	2,369
Petroleum exporting	2,147	11,963	3,658	5,002
Non-oil developing	1,596	1,697	7,252	7,372
MIDDLE EAST & CENTRAL ASIA				
Developing total	5,197	57,263	39,889	45,133
Petroleum exporting	7,597	62,800	47,070	51,891
Non-oil developing	2,400	5,537	7,180	6,763
OCEANIA & EAST ASIA				
Developing total	5,646	8,473	11,715	2,121
Petroleum exporting	96	4,379	3,148	4,029
Non-oil developing	5,742	12,870	14,863	6,150

[4]Negative values indicate deficit in B.O.T.

Source: UN Statistical Year Book, 1977.

TABLE 2

WORLD CURRENT ACCOUNT BALANCES
(Billions of Dollars)

	1973	1974	1975	1976	1970-73	1974-75
OPEC[a]	3.0	63.5	35.5	44.0	1.5	47.7
Surbluw OECD[b]	12.8	12.0	27.4	18.6	7.9	19.3
Deficity OECD[c]	1.3	34.0	20.9	32.1	3.1	29.0
Non-Oil Developing	15.0	32.5	44.0	34.0	15.0	38.8
Statistical Discrepancies[d]	4.5	1.5	19.5	17.0	6.5	12.5
Total Deficits	28.4	85.5	89.7	87.7	20.5	86.9

[a]Algeria, Equador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, U.A.E., and Venezuela.

[b]Germany, Japan, Belgium, Netherlands, Switzerland, and United States.

[c]Australia, Austria, Canada, Denmark, Finland, France, Greece, Iceland, Italy, Luxembourg, New Zealand, Norway, Portugal, Spain, Sweden, and United Kingdom.

[d]Attributed to asymmetrics in national reportings of balance of payments data. For details, see Organization for Economic Co-operation and Development, Economic Outlook, July 1977, Technical Annex, pp. 152-53.

Source: Based on data in Organization for Economic Co-operation and Development, Economic Outlook, July 1977, p. 69, 72-73.

TABLE 3

PERCENTAGE RATIO OF OUTSTANDING DISPERSED PUBLIC DEBT TO GNP OF PETROLEUM IMPORTING COUNTRIES

	1973	1974	1975	1976
Western Hemisphere	11.2	12.1	11.8	16.0
Sub-Saharan Africa	20.6	22.6	23.5	25.7
North Africa & South Asia	20.1	19.5	25.4	31.7
South Asia	17.8	16.8	17.8	19.6
East Asia & Oceania	12.3	11.5	14.0	15.2
TOTAL	14.0	14.0	16.4	18.2

Source: Department of Economic and Social Affairs, Supplement to the United Nations World Economic Survey, 1977. Recent Trends in World Economy, United Nations, 1978, p. 196.

TABLE 4

CURRENT ACCOUNT DEFICIT OF NON-OPEC DEVELOPING COUNTRIES

	1973	1974	1975
Current Account Deficity	-9.4	-30.6	-45.0
Increase in Deficity		21.2	14.4
Increase attributed to:			
1. Oil Price Increases		11.0	1.0
2. Food and Fertilizers		3.5	-1.0
3. Manufacturer's Price Increases and Other Trade Related Price Increases		6.7	13.8

Source: Roger D. Hansen, The US and World Development: Agenda for Action, 1976, Praeger Press, New York, NY, 1976.

These tables and Table 3 indicate the overall balance of trade, payments, debt service ratio (Table 3) and current account balances between OPEC and non-oil exporting countries have been widening quite dramatically. Also, the post-embargo increase in oil prices was a significant contributing factor to the additional import bill of non-OPEC developing countries, especially immediately after the 1973-74 embargo, (Table 4).

Finally, the ratio of outstanding dispersed public debt to the gross national product has increased for most fuel importing developing nations (Table 5).

Due to inadequate education and training, some of the developing countries waste a higher fraction of the exhaustible fuels they use than do developed countries, especially when operating capital--and fuel-intensive technologies. This waste by both industry and agri-business contributes to higher production costs, making Third World goods less competitive in world markets.

Problems Associated with Rural Electrification in the Third World

The efficiency of generating electrical power in most Third World countries compares unfavorably to electrical generating efficiency in most industrialized countries. Even in the developed world, at least half of all the electricity produced from exhaustible fuels never even reaches urban consumers because it is lost during conversion and refining in an increasingly inefficient fuel chain, which wastes, chiefly in the form of heat, two-thirds of the fuel (Reddy, 1980). Because of higher transmission losses, the wasted energy associated with Third World rural electrification projects is even greater and poses a difficult problem for developing countries attempting to bolster rural productivity.

In India, for example, only eleven percent of the 335,000 villages with population of under 500 have electricity or will be electrified in the next decade, while 25 percent of India's 600 million live there. Even those villages that eventually do become electrified will only be furnished with approximately 100 kilowatts a day or about one-tenth of the average electrical consumption in India's urban centers. In turn, this ten percent is largely consumed by the relatively "wealth" who represent about ten percent of the total rural population (Dunkerly, 1979). The present lack of electricity in rural India is indicative of the deficiency of public services in general throughout the rural sector and contributes to the decision of many to migrate into urban centers so that they can benefit from the perceived advantages of urban life.

Pattern of Rural to Urban Migration

In developing countries, the limited success of capital--and fuel intensive industrial and agri-business development has disrupted the socioeconomic structure of rural villages. Rural inhabitants, attracted by what they perceive as greater socioeconomic opportunities in the urban sector, have migrated into the cities. It should be recognized, however, that it is not only the "pull" of potentially increased social and economic opportunities which encourages rural migration but also lack of employment opportunities and the deterioration of mismanaged forests and farm lands which "push" villagers out of the rural sector. Such factors greatly aggravate the problems of unbalanced growth and employment in both rural and urban areas.

As rural villagers migrate to urban areas expecting increased job and public welfare opportunities, they often only find themselves a part

of the largely unskilled, unemployed urban mass. For example, in Latin America, one of the regions experiencing greatly accelerated rural-urban migration trends, the number of unemployed trippled in the 15 years from 1950 to 1965, climbing from 2.9 million to 8.8 million. The rate of visible unemployment increased from less than six percent to over 11 percent during this period.

The large scale migration of people from rural areas to urban centers accelerates the use of exhaustible fuels. In an urban environment, additional energy is required to satisfy increased food, fuel and transport need of the swollen urban population. Migration to urban areas has involved a substitution away from more traditional sources of energy such as wood, dung, leaves, human or animal labor towards kerosene, natural gas, coal and gasoline. Generally, it has involved a substitution away from human and draft power towards exhaustible fuel and electricity.

As the energy intensive urban population increases relative to the rural food producing population, each person remaining in the rural sectors must provide an ever-increasing surplus of agricultural products to support the mass of urban consumers. In the absence of a dramatic increase in agricultural productivity, the long standing hunger problem can also worsen if formerly self-sufficient rural inhabitants become convinced that social welfare opportunities are better in the nearest city.

To counter declining agricultural output and productivity, many Third World governments have subsidized or otherwise encouraged agribusiness to substitute exhaustible fuel-intensive mechanical energy for relatively unproductive labor inputs (ie. subsistence farmers).

Clearly, such policies have further displaced rural workers. Given

that exhaustible fuels are becoming increasingly scarce, especially in rural, Third World villages, it becomes difficult to justify continuing such a wholesale shift to mechanization and electrification in the presence of large numbers of unemployed rural workers.

Current Financial Assistance

Influence of financial assistance from the industrialized world's large financial institutions and consortiums have failed to solve the developing world's most critical problems. Although many governments, representing the industrialized world, and multi-national firms, have financially assisted in implanting relatively sophisticated exhaustible fuel-based-technologies in some Third World countries, these funds (mostly in the form of loans) are usually channelled to urban industries and subsequently have not been effectively circulated throughout all the economic sectors of developing countries who have opted for such industrial oriented development strategies.

Past technical and financial assistance has represented only a token effort on the part of the developed world. Moreover, if such exhaustible-fuel-based technologies and investment capital become obsolete as fossil fuel reserves approach exhaustion, such assistance hardly represents a significant long-run contribution on the part of the developed world to increase the Third World's permanent capital stock.

Developing countries have failed to benefit from such financial infusions because of inappropriate technical (ie. capital-intensive instead of labor-using technologies) and agricultural assistance accompanying such economic aid (eg. shipping mass quantities of wheat to non-wheat consuming populations, with few wheat-eating livestock and in inaccessible rural locations). Most of such top-to-bottom aid program will

fail to help rural, Third World populations until rural oriented financial and technical assistance can be directly channelled to local communities. Since many developing countries are characterized by arid or tropical climates, dispersed and inaccessible rural populations, an over-abundance of unemployed, unskilled labor and a lack of investment capital, any development strategy would need to focus particular attention to these attributes.

CHAPTER III

ECONOMIC THEORY

Using Exhaustible and Renewable Energy Resources

Before examining how various forms of renewable energy systems operate and which systems have been successfully applied in rural, Third World settings, there is a need to explore the theoretical implications of energy use on overall pattern of economic growth and development.

This chapter will show how economic principles can be applied when evaluating the potential costs and benefits associated with the development of various energy alternatives in rural, Third World settings. The first section traces the price trend for a particular exhaustible energy resource (petroleum) and draws some conclusions based on how prices and consumption rates for a particular energy resource affects various generations. The second section examines the intergenerational equity question and explores how future generations are affected by price trends during former generations.

Economic Theory of Using Exhaustible Energy Resources

Since developing countries have chosen to subsidize - or otherwise promote the development of large scale, exhaustible-fuel-intensive industries, much of the Third World has become increasingly dependent on not only exhaustible fuel imports but on fossil-fuel by-products and related technologies as indicated in the first chapter. Furthermore,

due to the widespread application of non-renewable based technologies throughout various economic sectors of many developing countries, an exhaustible-fuel-dependent infrastructure has begun to evolve in much of the Third World.

In addition, rapid industrialization has encouraged urban-based economic growth draining relatively scarce human, material and energy resources away from rural sectors. Such urban-based growth has resulted in increasing industrial and economic centralization due to the extraction and application of concentrated, exhaustible fuels and their related by-products. As will be shortly pointed out in an example, the use of exhaustible energy resources becomes more widespread over time as extraction and distribution costs are lowered due to applications of capital-intensive techniques and the realization of other product economies (i.e. the economies of large scale, specialization of labor, and application of mass production techniques) which are associated with most non-renewable-based technologies.

During formative generations, when exhaustible fuels and their related technologies were being discovered by today's industrialized countries, the costs of extracting exhaustible energy resources were relatively high with the demand for their use (ie. consumption) relatively low. However, as extractive and distributive, non-renewable-based technologies were developed, and various economies in production began to outspace the growth in market demand for exhaustible energy resources encouraging rapid economic growth. Thus, the present-day industrialized nations owe much of their currently high incomes per capita to the rapid decline in the relative cost of exhaustible fuels.

Graphically, such a decline in exhaustible fuel prices over time

TABLE 5

RELATIVE PRICES FOR FUEL AND LIGHTING

(Nominal Price for F & L/Price for all Other Commodities in the U.S.)[5]

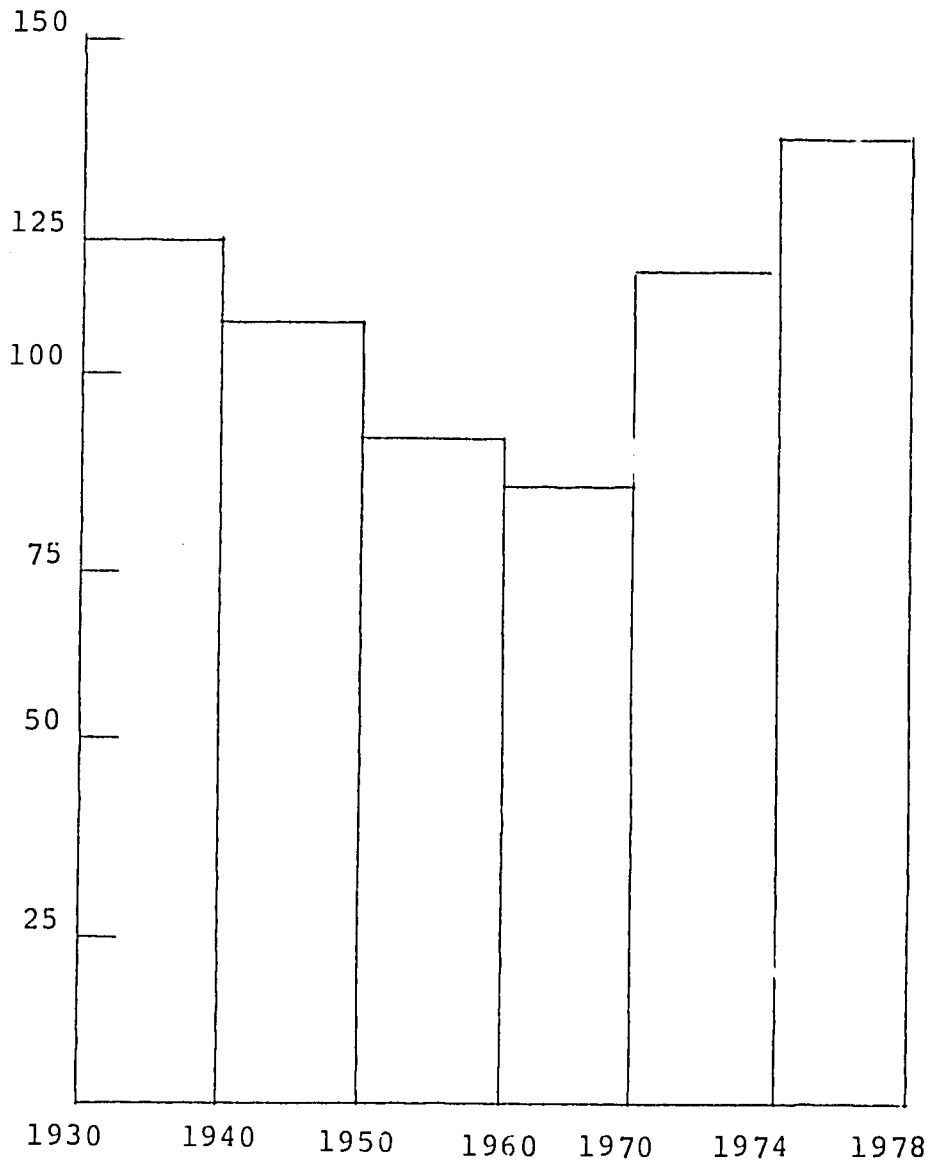
1830	118.2	1942	102.8	1954	96.2	1967	93.6
1931	120.4	1943	100.8	1955	97.5	1968	90.6
1932	140.0	1944	103.6	1956	16.7	1969	94.4
1933	131.1	1945	103.0	1957	99.3	1970	90.0
1934	126.5	1946	96.5	1958	94.2	1971	91.0
1935	119.0	1947	97.5	1959	94.0	1972	93.2
1936	122.1	1948	102.1	1960	94.9	1973	93.2
1937	116.8	1949	102.5	1961	96.2	1974	121.7
1938	125.8	1950	99.4	1962	95.1	1975	131.0
1939	122.7	1951	92.8	1963	95.1	1976	135.0
1940	118.8	1952	95.0	1964	92.6	1977	145.3
1941	112.9	1953	99.2	1965	92.2	1978	144.9
				1966	91.4		

[5]Viewed in terms of user costs, as defined by Marchall and Keynes, the discovery of the huge Eastern Texas Oil Fields in the U.S. during the 1930's touched off expectations of large negative user costs (ie. producer expect wellhead prices to decline). This occurred in an industry that at the time was relatively competitive--at least in the State of Texas at the wellhead stage. The result was disasterous rapid rate of exploitation of domestic oil fields which brought about the fulfillment of the expectations of rapidly declining wellhead prices relative to costs. This type of behavior among producers points out the fact that expectations of rapidly changing prices relative to costs is an exhaustible fuel industry can encourage behavior which will make the prophecy of declining wellhead prices in this case, self-fulfilling and can lead to gluts accompanied by wasteful or otherwise inefficient consumption patterns.

Source: Historical Statistics of the U.S. Colonial Time to Present. U.S. Department of Commerce, p. 199-201.

Figure I

Price Trend for Fuel and Lighting 1930-1978



Source: Historical Statistics of the U.S.: Colonial Times to Present.

can be depicted as a movement along the declining portion of a time adjustment path (TAP) for a particular exhaustible-fuel based industry (e.g. petroleum) as illustrated in figure 2. Table 5 provides some empirical evidence that the relative price trend for petroleum (as well as other exhaustible energy resources) has in fact been U-shaped, as depicted by the TAP (figure 2) for petroleum reserves, the industry's short-term average cost (AC) and marginal cost (MC) curves are at relatively high positions with world demand being relatively slack, represented by position 1. As petroleum exploration methods "improve" (i.e. lower risks and higher yields due to increasingly efficient operations and other economies of production) costs drop and the demand for petroleum begins to pick up until P_2 is the going world price, with Q_2 quantities of the total petroleum stock having been consumed up to this point (position 2). This process continues until P_m, the minimum price is reached which corresponds to the TAP and AC minimum tangency points (position 4).

Although it is assumed that there have been equal downward movements along the TAP curve (from 1 to 2 and 2 and 3), the quantity of petroleum being consumed accelerates due to the decline in world prices as producers begin realizing technological progress and increasing returns to scale.[6] Eventually, the world's petroleum extractive industries begin

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[6]Simply put, increasing returns to scale generally characterizes the long-run average cost curve for decreasing cost industries (or in terms of TAP: Q_1 Q_2 Q_3 Q_4). For petroleum and most other exhaustible fuel related industries the rate at which a firm experiences increasing returns to scale is determined by how quickly the various economies of production that are gained by way of technological progress, out pace the losses associated with depleting relatively accessible higher grade fuel reserves. However, this assumption has been challenged in light of emerging material (e.g. fuel and metal scarcities and also high inflationary and interest rates) and environmental (e.g. air and water pollution) constraints.

tapping lower grade deposits as more accessible, higher quality reserves approach exhaustion.

As the world's petroleum extractive industries begin tapping less accessible and lower grade deposits, they begin facing increasing fuel, capital and general operating costs. The higher costs are then passed along such that world prices for petroleum begin to rise.

However, due to the scarcity of information on how to use alternative source of energy,[7] world demand for petroleum keeps growing as newly entering consumers (e.g. developing countries) begin to express their demand for petroleum. Even if it is assumed that the growth in the world demand for petroleum stays relatively constant[8] after position 4, the portion of the petroleum stock remains for any generation, after position 4, is clearly less than the portion which generations 3 through 4 consumed.

Exhaustible Fuel Use and Intergenerational Equity

The accelerated depletion of exhaustible energy resources such as petroleum, by former generations (generations 1 through 4) suggests

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[7]Such a scarcity of inflation on how to use alternative sources of energy can be attributed to several causes. The first, and perhaps the foremost, reason involves the action of an energy resource owner who wishes to maximize the future value of his energy stock. Given that by attempting to limit or otherwise neglecting to inform consumers of his resource stock on how to use alternative sources of energy or other exhaustible fuel saving methods, the resource owner can keep the demand for his resource stock relatively inelastic.

[8]More realistically, however, it is expected that as better quality of exhaustible fuel deposits (such as petroleum) approach exhaustion the demand for fuel would tend to accelerate since remaining fuel stocks are still lower quality (i.e. need to extract increasing amounts, in terms of mass or volume) to obtain the same BTU content as higher quality fuel.

that newly entering latter generations of petroleum consumers and producers will have smaller share of the petroleum stock to consume at relatively higher world prices. As a result, generations 5 and 6, who might represent developing countries that have started to develop petroleum dependent industries, will face increasing social costs[9] as exhaustible fuel stocks are increasingly depleted.

Given that the relative price mechanism is unable completely to reflect the demand of future generations for remaining petroleum energy stock, the increasing pecuniary and social costs of "over depending"[10] on formerly inexpensive petroleum supplies must be borne by latter generations (ie. generations after position 4).

Thus, in a sense, market latecomers (eg. developing countries) are penalized for failing to develop their petroleum related industries when the cost of extracting petroleum was decreasing. This points out the need for Third World countries to explore and develop alternative-

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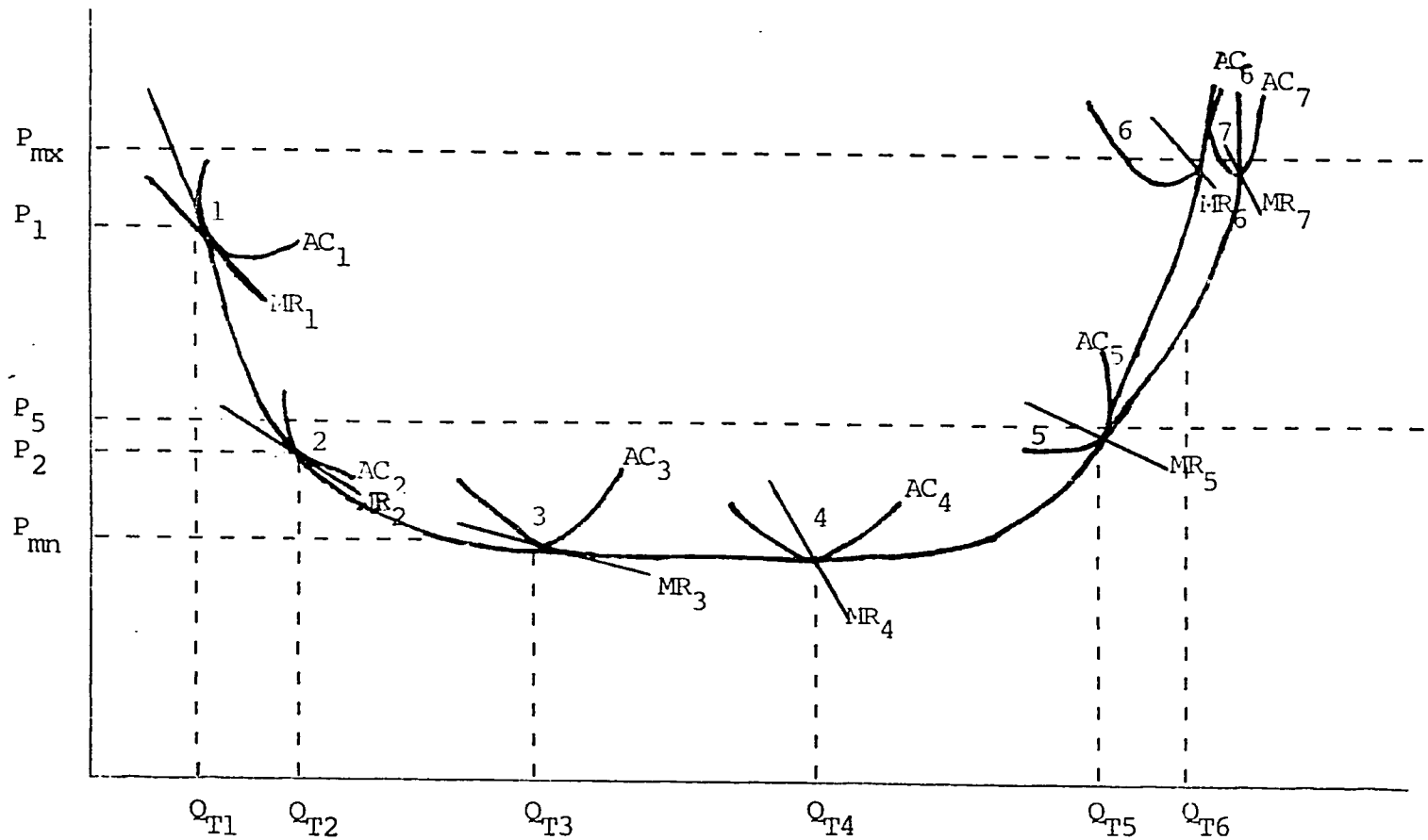
[9]Some of the social costs which latter generations may have to hear include: increasing environmental degradation (eg. air, water and radioactive pollution) as capital and fuel intensive technologies continue to be developed ignoring pecuniary, material and environmental constraints; lower standards of living as eco-system begin to collapse as a result of attempting to support increased numbers of people desiring higher standards of living and affluence in the face of diminishing stock of land and energy resources.

[10]As the cost for exhaustible fuel decreases dramatically, the tendency to substitute more convenient, fuel-intensive activities for more mundane, time-consuming albeit energy efficient methods (eg. drying clothes with an electric dryer as opposed to air drying) increases. This serves to accelerate the rate at which a community evolves into an exhaustible fuel dependent society enjoying relatively high levels of material affluence and convenient short-run, and away from a more energy efficient and exhaustible fuel conserving society that grows at a slow but steady rate.

TIME ADJUSTMENT PATH FOR U.S. PETROLEUM INDUSTRY

Fig. 2



Position 6 - Oil Embargo, OPEC Cartel Scenerio

Position 7 - Politically Controlled prices (at below the market price)

energy-technologies[11] instead of increasing their dependence on exhaustible fuel stocks which can be "unintentionally squandered[12] by previous generations. It is hoped that Third World can begin developing such alternatives before the social costs associated with postponding a transition away from petroleum and other sources of exhaustible fuels become too great.

Until recently, the assumption has been that since technological progress will continue to outpace energy and general resource scarcity and properly functioning market economy would ensure that future generations (especially in rural, Third World settings) effectively use the massive accumulation of fuel- and capital-intensive technologies as non-renewable fuel resources approach exhaustion, becomes more difficult. Therefore, since the demand by future generations for more sustainable sources of energy cannot be expressed during former generations, the development of such sources of energy must be initiated by previous generations.

Many would argue, however, that if alternative-energy systems were in fact competitive to non-renewable-based technologies, rising exhaustible fuel prices would, at least in the long-run, be the very mechanism that would permit the unimpeded development of such alternatives by future

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[11]Alternative-energy-technologies inclue any experimentally proven or other potentially viable technology that can best tap previously under developed source of energy (oil shale, tar sands, geo-pressurized methane, wind or solar power, alcohol and other biofuels).

[12]When exhaustible fuel prices are politically controlled at too low level (which encourages current consumption reads) the inevitable result is overdependence on a few exhaustible sources of energy inducing fewer technological substitutions in processes, products and services. (See Robert V. Aryee's "Resources, Environment and Economics, John Wiley and Sons, New York, 1975, p. 51-52 for more exploration.)

generations. However, not only does this argument fail to consider the scarcity of information on the development potential of many alternative-energy-technologies but it also ignores the relatively lower discounted rate of return[13] on the initial capital investment outlay associated with many alternative-energy-technologies.

However, if this fact had been recognized by "energy planners" prior to the drastic jump in the price for petroleum (which future generations face), at least among the industrialized countries who might have more easily sacrified some economic growth in the short-run so that they would be able to consume a steadier more continuous flow of energy in the long run; a "fuel stock tax"[14] might have been imposed after position 4 on the TAP. Such tax would have the effect of raising the price of petroleum or other exhaustible fuels so that the long-run historical price for such fuel stock could be stabilized.

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[13]Market decisions with regard to the allocation of energy resources as measured by the relative valuation of various energy technologies, tend to be shortsighted since the discounted rate of future returns on many alternative-energy-technologies are often understated. The expected discounted returns from many alternative technologies are usually discounted at the going rate of interest regardless of the fact that some technologies become relatively more costly to operate overtime since they are powered by increasingly expensive exhaustible fuels. (See William Ophulus', Ecology and Politics of Scarcity, W. H. Freeman & Co., San Francisco, 1977, p. 169).

[14]According to Pigou (See Economic of Welfare, 1932) marginal social costs always exceed marginal private costs in an increasing costs industry. Marginal social cost can be defined as the sum of the marginal private cost of producing a commodity, plus the "nonrecoverable" positive and negative "effect" (i.e. externalities) associated with an increment of output of that commodity which accrue to or are borne by individuals outside the industry. If an increasing cost industry is taxed, its marginal private cost can be raised until it equals its marginal social cost. Ideally, in the case of an exhaustible fuel related industry such a tax could be tied to the development of alternative energy system as opposed to relying too heavily on the output of any increasing cost industry (e.g. petroleum).

The increased price for fuels could therefore encourage earlier development of alternative-energy-technologies as well as more conservation and efficient use (i.e. less waste) of remaining reserves. Not only does less waste lessen the social cost for future generations but if alternative-energy-technologies had begun to be developed before position 4, the returns from such technologies, to future generation, could start to be realized before position. Thus, by developing alternative-energy-technologies at an early enough time, the disruptive effects of rapidly rising fuel prices as it becomes more costly to extract less accessible petroleum reserves, could be minimized.

Considering that many developing countries who have already started large scale industrialization projects are becoming increasingly dependent on exhaustible-fuel-intensive "advanced" technologies, the institutional difficulties of imposing such a fuel stock tax on infant domestic industries, who are facing greatly increased fuel costs, may be insurmountable. However, Third World "energy developers" should realize that as more non-renewable-based-technologies are imported to promote industrial development, they will become dependent on developed countries for these capital and fuel-intensive technologies.

Also given that many developing countries have few indigenous, exhaustible fuel reserves, the Third World countries will need to develop indigenous sources of energy and accompanying conversion technologies in order to continue balanced, diversified growth without contributing to the disruptive effects of worsening balance of payments position. (Not to mention exacerbating the increasing social, environmental and general economic costs that future generations must bear if a transition away from exhaustible fuels is postponed).

Such alternative-energy-technologies should be developed in such

a way that their continued use and improvement by latter generations is ensured without forcing future Third World inhabitants through yet another costly transitional squeeze.

The inability of the future Third World generations to cost effectively use "recycled," the non-renewable-based capital stock (which they will inherit if they pursue development paths similar to the ones chosen by today's industrialized countries) represents another potentially burdensome social cost.[15] Since the demand for more capital intensive, non-renewable-based technologies start to grow faster than the rate at which exhaustible fuel can be produced, higher quality, relatively accessible reserves are gradually depleted.

Consequently, due to the continued strong dependence on oil, as well as other exhaustible fuels, world petroleum related industries are induced to continually raise the price for their products.[16]

Although the central tenant in economics concerns itself with the optimal allocation of "scarce" (i.e. exhaustible) resources towards competing uses, many economic models have chosen to ignore or assume away the problems that begin to confront future generations once a significant portion of those resources approach exhaustion. Implicit, though rarely

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[15] This assumes that developing countries are entering increasing cost (e.g. exhaustible fuel related) industries and that there is a divergence between the private and social cost associated with "inefficiently" using exhaustible resources. Given such a condition, the rate at which the demand for any exhaustible fuel grows will determine how quickly the price for that fuel increases.

[16] The first substantial round of price increases largely initiated by the OPEC cartel immediately following the 1973-74 Arab Oil Embargo may have been the turning point (corresponding to position 4 on the TAP) with respect to the price trend for petroleum.

stated in many areas of economic analysis, is the pre-assumption that certain scarce resources stocks approach exhaustion, any properly function price system will ensure that formerly costly, large scale, "advanced" technologies will become economically competitive.

This enables various exhaustible fuel dependent industries to substitute towards larger scale, more capital-intensive technologies, so that they can tape or make better use of resources that are less accessible or of lower quality. However, such a presumption, namely that the economies of large scale will, in the long-run, lower the cost of tapping such resource stocks.

CHAPTER IV

RENEWABLE ENERGY RESOURCES

Renewable energy resources are non-depletable and will be available indefinitely. By far, the world's most inexhaustible source of energy is solar energy, which can be harnessed both in the direct form of sunlight or in more indirect forms as the energy stored in the wind, plants, and water impounded in elevated reservoirs.

Solar energy drives the earth's climatic system and assumes many forms in addition to that of direct sunlight. For example, the kinetic energy co-attained in the winds is induced and sustained by the uneven heating of the earth's surface by the sun. Living plants convert sunlight to chemical energy through the process of photosynthesis. Hydroelectric energy, the kinetic energy of falling water, is made available on a renewable basis by the solar-powered evaporation of water. Ocean thermal gradients, another potential renewable energy source, arise due to the solar heating of ocean surface water, coupled with the large-scale circulation of ocean waters driven by the sun. Other indirect sources of solar energy, are waves, ocean currents, and salinity gradients.

Prospects for Major Approaches to Solar Utilization

(1) Solar Thermal Energy: The simplest method of harnessing solar energy is to collect and utilize it in the form of heat. The captured thermal energy can be used to perform a variety of tasks spanning a broad

range of required temperatures. Relatively low temperatures (less than about 212°F) tasks include domestic water heating, building heating, air conditioning and agricultural crop drying. The utilization of solar energy for residential and commercial water heating, building heating and cooling, and industrial process heat applications can be of major significance, because taken together, these tasks account for nearly half of all energy currently used in the world.

(2) Solar Thermal-Electric Conversion: Solar thermal-electric systems convert heat to electricity by means of conventional steam turbine generators or heat engines. In addition to providing electricity, solar-powered heat engines can provide mechanical energy for applications such as pumping water for irrigation. Solar thermal conversion systems can be built or variety of scales ranging from small-scale residential installations to large, centralized power stations. While most of the emphasis to date has been placed on large-scale designs, smaller systems, perhaps built on a community scale, hold considerable promise. A major advantage held by smaller systems located near their load is the utilization of the heat left over from electric conversion is greatly facilitated. In fact, "total energy" systems--capable of providing both useful thermal energy and electricity for residential, commercial and industrial use, constitute one of the most promising approaches to solar energy utilization.

Photovotaic Cells: Photovoitaic cells, commonly called Solar Cells, are semi conductor devices that can convert sunlight directly into electricity. These devices are attractive for a number of reasons. They have no moving parts and therefore are quite reliable, require little maintenance, and have potential for long useful lives. Electrical generation

produces no pollution and consumes no water.

Wind Energy: The uneven heating of the earth's surface by the sun gives rise to the large-scale motion of the atmosphere referred to as the winds. The winds thus represent solar energy temporarily converted into the kinetic energy of air. This kinetic energy is continually replenished by solar radiation and continually dissipated by frictional process that result in atmosphere heating.

In recent years, there had been renewed interest in harnessing wind power, owing chiefly to high fuel prices, an increased awareness of the environmental problems associated with conventional energy sources, and several attractive features of the wind resource. Wind represents a large and non depletable energy resource that can be utilized with minimal impact on the environment, producing no air and thermal pollution and requiring no water in its utilization. The simplicity of wind technology will allow for rapid development in comparison to many other energy technologies. Finally, the economic prospects of wind systems are quite promising.

Hydro Electric: Hydroelectric power represents a form of stored solar energy that is, in principle, a renewable source of energy. In the course of the hydrologic cycle, water from lakes and oceans is evaporated by the sun. It is eventually turned to the land as rain. Impounded behind dams, it has stored gravitational energy and allowed to flow through turbine to useful mechanical or electrical energy.

Biomass: Photosynthesis is the biological process by which green plants convert sunlight into organic matter. The biomass resource consists of the chemical energy stored within organic matter originally derived from the photosynthesis process. The average energy content

of raw, dry biomass is about 15 million Btu's per ton. Roughly 0.1 to 0.2 percent of the energy falling on earth is captured by plants. Although this percentage is small, the world biomass energy resource is quite larger; on annual basis, biomass production is about seventeen times greater than worldwide nonfood energy use. In many developing countries, wood, charcoal, and cow dung are primary fuels used in rural areas.

Ocean Thermal Energy Conversion (OTEC): The ocean, occupying 70 percent of the global surface area, acts as vast natural collectors and storage reservoirs for solar energy. Heating by the sun produces temperature differences between the warmer ocean surface waters and the cooler, deeper layers 2,000 to 3,000 feet below the surface. These temperature differences are maintained by the large scale circulation of the ocean's waters, driven by the sun, and attain their largest and most stable values of about 30°F in tropical water 20° latitude of the equator. Ocean thermal energy conversion system seek to derive useful energy from these thermal gradients. The principal attraction offered by OTEC is the fact that the ocean itself both collects and stores solar energy, obviating the need for these two components, generally essential to the solar energy systems.

CHAPTER V

THE DEVELOPMENT OF RENEWABLE SOURCES OF ENERGY AND APPLICATION OF RENEWABLE-BASED-TECHNOLOGIES IN RURAL THIRD WORLD SETTINGS

Wind Energy Development

Developing countries may not have to rely on more "advanced" technologies in order to store sunlight. Rural communities may be able to make use of uneven heating in the earth's atmosphere instead. The winds are an indirect source of solar energy which result when hot and cool air masses combine in the atmosphere. The energy released as a result of this combination or mixture of hot and cool air is especially strong in certain topographic regions (eg. artic and subartic areas, mountain tops and valleys or high plateau regions particularly on the western hemisphere). These topographic features can be found within the boarders of many developing countries. Finally, just as there are global sunbelt regions, two major wind belts provide many developing countries with steady, seasonal trade winds which coincide with harvesting seasons when agricultural energy and labor are at a peak.

Most solar energy systems collect and convert radiant energy into thermal energy (eg. flat plate or focusing collectors) or converts the radiant energy into electricity (eg. photovotaice). A wind energy system on the other hand converts kinetic energy into electrical energy or directly into mechanical work. Thus, after kinetic wind energy has been converted into usable form, the resulting power can be applied to power turbines,

pumps, compressors or other machinery that increase rural, Third World productivity. As a source of energy, the use of wind energy is inexhaustible and pollution-free as other more direct methods of using sunlight.

In general, a windmill can be classified as either horizontal axis machine (in which the vanes rotate about a horizontal axis) or a vertical axis machine. Windmills intended for pumping applications are required to rotate relatively slowly and regularly, have a large number of vanes; whereas windmills intended for electrical generation rotate rapidly and usually only have two or three vanes.

For developing countries, the crucial question when evaluating the development potential of wind or other solar energy systems becomes, how much energy will be gained per dollar of investment? Increases in energy gained exceeds the costs of planning, building and maintaining a wind energy system (assuming that pecuniary costs are a good reflection of the actual opportunity costs associated with the development of a wind energy system).

Because of wind availability, windmills cannot be solely relied upon for electrical production but can still be used as an important supplemental source.[17]

However, windmills can still be used to satisfy various primary operations such as grain grinding, agricultural churning, water pumping, dredging and irrigation.

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[17] If rural inhabitants were willing to adapt their lifestyles such that they could accommodate wind variations and perform these agricultural tasks, when wind conditions were "optional," they would not only be able to significantly increase agricultural productivity but rely on wind power for a bulk of their work.

Wind Powered Irrigation and Electrification

As already mentioned, most Third World Agri-businesses currently make wide use of exhaustible fuel-intensive machinery, pesticides and petro-chemical fertilizers. Many of these agricultural practices require the support of other primary agricultural operations (eg. irrigation and dredging equipment). Wind powered irrigation systems are, for the most part, land and labor intensive. Also, since relatively simple construction, operating and maintenance techniques are used, "semi-trained" workers at modest capital outlays, also allow participating villagers who formerly kept only a relatively small parcel of land under cultivation to bring more land under cultivation. By expanding the area which is to be brought under cultivation, rural villagers can increase agricultural output as well as rural productivity.

The production of energy from windmills designed specifically to operate in low wind velocities that usually prevail in India during the main irrigation season, is estimated to be reasonably economical for irrigating small farms from open wells. More economic benefits could be realized if irrigation was practiced all year round, especially in the hot summer season. Currently, this is not done because of the high cost of pumping water from deeply entrenched ground water: wind irrigation practices could greatly benefit developing nations.

The cost of developing a wind irrigation system ranges from an initial $1,600 (not including the sails and spare which are made from canvas and bamboo) down to a reproduction cost of about $1,180 if the system components are mass produced in batches of about 100 units. The six sails used, cost a total of $47.00 and only need to be replaced every

two months if used all year round. The pump costing $95.00, may also need to be replaced every five or ten years. The life of the basic structure may be around 25 to 30 years. When such a design is used, maintenance costs are virtually eliminated except for those costs associated with an occasional, perhaps biannual inspection and greasing (Batton, 1979).

Finally, the U.S.-Tanzanian NAAS study showed the cost of wind generated electricity was about 1.5 shillings or about $0.18 per kilowatt hours (Earl, 1975).

Small Scale Wind System

Cost effective development of wind machines does not necessarily require the use of large turbines. Smaller windmills might be easier to locate in villages, thus, reducing transmission costs. Smaller scale wind systems can produce power in much lower wind velocities than large ones do and can operate over a longer period of time. Since the cost of a windmill and related mill installation costs per kilowatt become cost competitive at relatively lower power capacities (between five and ten kilowatts) they represent an important and relatively inexpensive source of power for rural, Third World communities. On a small scale, wind power can be inexpensively harvested by windmills to perform any kind of work other than just electrical generation. For example, in the valley of Lasithi, on the Island of Crete, the inhabitants use an estimated 10,000 small windmills, which catch the wind with triangular bands of white sail cloth, to pump water (Clark, 1974).

Small scale windmills, built with local materials have recently been erected in East Africa. Recent adaption of ancient Cretion windmill

designs have been built in many rural, Third World regions using local materials. The introduction of wind powered irrigation has allowed the Gelebs in Southern Ethiopia and farmers along Lake Rudolph in Kenya to quadruple agricultural output (Goulet, 1980). In the People's Republic of China, windmills are currently used for irrigation on small holdings, using windmill driven scoop-bucket systems. The windmills are constructed of locally available materials, bamboos and wood, and are generally built by the users. With minor modifications, the same device is used to grind beans and rice and for shelling crops, as well as for pumping water.

In Thailand, simple windmill constructed locally, with wooden or bamboo poles and cloth sails, have been used for many years to move water; more recently a two-bladed, wooden-propellor type of windmill has been introduced. In this case, the water is lifted by scoop-buckets attached to an endless belt or by a "water ladder" (Clark, 1974).

The new Alchemy Institute of Massachusetts, working with the Indian Institute of Agricultural Research and the Indian National Aeronautical Laboratory, has developed a 25-foot sail wind pump for rural use; employing the whell of a bullock cart as a bub and bamboo frame for the cloth sails. This simple device is expected to provide a cost competitive power for Indian villages (Sharrat, 1978). At the Indian Institute of Science in Bangolore, a vertical axis windmill with savonius type rotor was chosen to meet the criterion of low cost and high starting time. The rotor consists of cloth sails stiffened by ropes (made with local materials) which are attached to circular boards at the top and bottom. The choice of cloth and ropes as materials for the rotor permits the sails to be shaped such that they achieve reasonable efficiency and high stability (Sharrat, 1978).

Wind Storage and Wind - Solar Combination Technologies

West Germany and Denmark have already started experiments in wind power storage by using surplus wind energy to power pumps or turbines that compress air into underground caverns (Agarival, 1978). In addition, currently more costly and technically complex storage methods (eg. wind-powered hydrogen generations via electrolysis or more advanced battery technologies that can chemically store surplus electrical energy) may become economically attractive, in the long-run; as exhaustible fuel prices continue to escalate. If such storage technologies, in fact, prove successful in the long-run, the idle-time costs associated with wind energy systems could be substantially reduced.

In many areas scattered throughout the Third World, wind speeds and sunshine are negatively correlated (ie. wind speeds being highest when the sun is not shining). This suggests that an optimum "technological mix" would use wind and solar systems in a complementary idle capacity minimizing fashion, each system backing the other up. In this way, one of the inherent drawbacks associated with solar and wind energy systems, (namely, the idle capacity problem when there are not sufficient levels of sunlight or wind) could be circumvented, resulting in reduced operating and lifecycle costs for the user.

The Brace Research Institute, a leading international energy research center based in Canada, has maintained a research laboratory on the Island of Barbados to build experimental wind and solar machines. The work is still continuing there, where recent projects have included construction of a special solar-powered cooker for a school in Haiti and the fabrication of special solar-powered water distillation units

as well as installation of various types of wind machines for all purpose water pumping. The Barbados government has not only sanctioned the Brace Institute's projects, especially for wind and solar technological combinations, but would like to include such projects in a comprehensive agricultural development program (Hayes, 1980).

All things considered, the high conversion efficiency of transforming wind energy into mechanical work accompanied by relatively low social and environmental costs (i.e. no deleterious inputs or wastes and little noise) make wind power attractive, and long-run supplement to a well integrated and diversified energy strategy for most Third World communities that satisfy minimum climatic requirements.

Hydro-Power Development

Water of hydro power is essentially another form of solar energy. The sun begins the hydrologic cycle by evaporating water from lakes, seas, the ocean and other large bodies of water, letting resulting water vapor rise on a current of heated air. The cycle continues when the water vapor reaches a certain altitude and, depending on temperature conditions, condenses as precipitation back onto the earth's surface. The potential energy of the falling water gradually dissipates as the water flows back to the seas and oceans. Therefore, it can be considered that the energy potential of water flowing down from an elevation above sea level is essentially another renewable and "direct" manifestation of solar energy.

From 80 to 90 percent of controlled water energy can usually be converted into useful work. This compares rather favorably with the efficiencies of most other solar, chemical or thermal energy system which

range between 25 to 45 percent (Miccolis, 1978). The world's industrialized regions possess about 30 percent of the earth's hydro-electric potential, as measured by conventional criterion, but produce 80 percent of all its hydro-electricity. In contrast, Africa is endowed with 22 percent of all hydro-electric potential, but produces only 2 percent of all hydro-electricity, about half of which is from the Aswan High Dam in Egypt, the Akosombo Dam in Ghana, and the Dariba Dam on the Sambezi River between Zambia and Rhodesia (Wilson, 1978).

Low head[18] hydro power can provide power that is relatively easy to control and maintain, at relatively high efficiencies in most rural Third World settings. Much of the extensive hydro-electric development even in such industrialized countries as Japan, Switzerland and Sweden has entailed the use of comparatively small facilities, such small units hold continuing promise for developing countries. In mountainous, headwater areas, such as Nepal and India, where relatively small volumes of water fall great distances, numerous choice sites exist for small stations up to 100 megawatts each (Clark, 1974). The most efficient development in low head hydro-electric generation is the emergence of thousands of small, rural stations throughout China. While the state provinces provide limited assistance in design, equipment and training of operators, most of the funds, labor and construction materials are exclusively local. The small stations are instrumental in the rudimentary electrification of the Chinese country-side (Smil, 1980).

China reportedly has 60,000 small facilities that together generate

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[18] Low head hydro simply refers to the fact that the waterflow in question is "falling" (usually measured in cubic feet per second) a comparatively short distance. Since the "head" or height of waterfall determines the size and type of water wheel or turbine that will be chosen, the lower head, the smaller and less sophisticated the waterwheel or turbine will need to be.

over two million kilowatts, about 20 percent of China's total electricity capacity. The Chinese facilities are located, for the most part, in sparsely populated areas, thereby neutralizing the prohibitive transmission cost of sending electricity from large, centralized facilities to down field rural users. Local workers built the small earth-filled or rock-filled dams that provide substantial flood control and irrigation benefits (Smil, 1980) which represent important externalities that could help increase agricultural productivity in other Third World communities. Recently, Kenya received financing from the World Bank to build six, 60 megawatt installation on the Tana River.

In Nepal, site of the world's worst rates of deforestation and its attendant calamities, a NAAS sponsored workshop found that mini-hydro could be used to provide energy in combination with a woodlot to produce nitrogen-based fertilizer essential in reforestation programs. The workshop found out that "for a typical hill village of 250 persons, 10 - 18 killowatt mini-hydro and a 30 - 40 hectare managed woodlot can provide significant irrigation, fertilizer, domestic water supply, lighting and small industry returns as well as having enormous social benefits (Todaro, 1977).

Environmental, Economic and Other Attributes Associated with Small-Scale Hydro-Power

The environmental effects of small scale, hydro-power are generally less adverse than those of exhaustible fuel intensive, thermal power plants. Unlike most fuel intensive, thermal electric plants, small scale hydro facilities are particularly well-suited for meeting agricultural demands during the main harvesting season in most rural Third World regions. The operating and maintenance costs of small hydro facilities are also

found to be generally lower than those of most thermal electric generating plants.

In terms of cost per kilowatt hour based on U.S.-Tanzania NAAS study, small scale hydro-power facilities were shown to generate electricity in rural areas for between 0.26 to 0.97 shillings or about 0.03 to $0.12 (Wilson, 1978). In addition, small scale hydro installation break down less often than other types of generating equipment. Although as already mentioned, few Third World agricultural processes actually require electricity, because of the low cost and high efficiency (85 or more) of converting water power into electric energy, the development of small scale hydro-electric facilities appear to be a good means of providing the Third World communities with electricity. This of course assumes that villages are located near a reliable waterflow that can be developed in a relatively simple fashion maximizing the use of local labor and materials.

It seems that the use of dams as storage midums may be the most effective way to minimize the idle times inherent with both solar and wind systems. For example, a combination[19] of wind and hydro-electric power could be used to minimize the idle times of wind conversion technologies.

Finally, by dispersing hydro-power sites all over the countryside, as opposed to locating a few plants in central locations, rural villagers could acquire greater access to the total hydro-electric potential of any region. In general, smaller dams can be instruments of economic equity, given that the greatest potential for future small scale hydro-

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[19] Surplus hydro-electric power can be used to pump water from lower reservoirs to an elevated one; as power is drawn, the water is allowed to flow back to the lower pool.

power development lies in rural, Third World regions currently lacking adequate supply of energy.

If a number of rural communities begin developing hydro and other renewable energy systems and establish them as leading economic base sectors[20] it means, among other things, that inaccessible and widely dispersed Third World villages will be able to make use of the renewable agricultural systems generally do not need to rely on capital and fuel intensive technologies as much as more centralized industrial based regions do.

Solar Cookers

Solar cookers represent one of the most simple (in terms of both maintenance and operation), direct and necessary applications of the Third World's solar energy potential. By using solar cookers, varying surface temperatures can be attained suitable for most cooking requirements. Although solar cooking devices have been introduced in the past, widespread use has been impeded, due chiefly to the formerly high costs (up to twenty-five dollars per unit in the 1960's) as well as cultural resistance to abandoning the traditional use of firewood for cooking. Currently however, heap new reflecting materials (eg. aluminated mylar) can be stretched over inexpensive, locally made frames (Revelle, 1976). Such cost reductions have encouraged villages who are facing firewood

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[20] A leading economic base sector can be described as the sector which acts as the "engine" or growth within a region. That is, the base sector of many community is the sector that adds the greatest value to the raw materials and capital that it uses and provides necessary inputs as well as other goods and services that supports the growth of other community industries. In general, energy related industries are good examples of leading economic base sectors.

scarcities to change their cooking habits.

The first in a series of 1,000 solar stoves has been used on a experimental basis in China and is currently being used successfully by peasants for cooking and other household needs at the outskirts of Shanghai.[21]

The problem that now remains with solar cookers and stoves is the inability to use them during cloudy periods and in the night which has contributed to cultural resistance in many areas. Therefore, until cost effective heat storage technologies for solar cookers can be developed, cookers will continue to be used only in supplementary manners. Although the introduction of solar cookers in India, Mexico and Morrocco have not yet resulted in social acceptance of new methods and styles of cooking, in other developing countries, solar cooking has proven to be a popular novelty. It may be possible that better energy storage technologies and heat transfer techniques to permit indoor or evening cooking accompanied by more widespread understanding and use of solar cooking techniques (as well as cost effective applications of other renewable-based-technologies) may help solve the remaining exhaustible fuel and firewood scarce, rural Third World regions.

Of course, the escalating costs of conventional fuels as well as increasing scarce firewood supplies, are the best mechanism encouraging a substitution towards more direct uses of any renewable based technology.

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[21]Smil suggests that the rural regions in the immediate vicinity of large urban centers are in the best position to benefit from solar-related research and development activities. (See China's Energy, Praeger Publishers, 1976).

Solar Water Heating

The use of solar energy to heat water is another relatively simple and cost effective use of solar generated that could make a significant contribution to health and well being of rural villages. Solar heated water for dishwashing and bathing can reduce the burden of infectious diseases, and clothes washed with soap and hot water outlasts clothes beaten-clean on rocks at a river's edge (Revelle, 1976). Flat plate solar water heaters can be manufactured rather easily with materials that are either indigenous to the Third World or have been recycled elsewhere. The most favorable conditions for the development of small scale water heaters exists on the high Tibetan plateau, where the average number of "sunhours" is about 3,000 accompanied by low humidity and low turbidity, conditions that normally interfere with the collection of sunlight (Revelle, 1976). A 280 square meter glass solar heat absorber currently heats water for a public bath in the Tibetan capital of Lhasa. Similar smaller units, as well as solar stoves for heating and cooking, are operating elsewhere in Tibet (Earl, 1975).

Solar Distillation and Desalination

Where the water is contaminated, solar distillation may well be the most cost effective[22] way to provide some drinking water for rural villages. Although there are numerous designs, a simple water distillation unit consists of a box in which sits a suspended black tray where the dirty water rests, covered by a clear sloping glass plate. Water

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[22]Solar distillation requires a relatively large capital investment per unit of capacity but properly designed and constructed systems, a minimum of operating and maintenance costs.

is evaporized by sunlight and condenses on the glass, then trickles down the walls of the still into clean containers at its base. This type of stills requires little maintenance or capital outlays and yields up to four liters (42 quarts of drinking water per square meter of glass) per day (U.S. Academy of Sciences, 1979).

Sun powered desalination stills that produce fresh water would greatly benefit arid regions of areas experiencing desertification. A simple distillation plant in the Kyzyl-kum Desert, located in the Soviet state of Turkemenia produces four tons of drinking water a day (Steward, 1979). The installation consists of slanted pipes filled with salt water pumped out of deep wells. The pipes are covered with heat absorbing screens and as the pipes heat up, the water settles at the bottom of the pipes and the upper ends fill with condensation. This condensation in turn produces fresh, drinking water.

Salt for food preservation is an important by-product of desalination of blackish ground and sea water, helping to lower input costs for other regional industries (especially in tropical areas where salt is used to preserve food). Solar desalination farms on desert lakes could provide arid, developing countries with an important source of both salt and water.

Solar Crop Drying

Just as solar cooking, water heating, distillation of solar energy could be greatly expanded, solar drying of agricultural products is already one of the oldest and most widespread techniques of using sunlight directly.

Traditional solar crop drying involves spreading the material to

be dried in a thin layer on the ground exposing the crops to sun and wind. Copra, cocoa grain, hay, fruits and vegetables are still dried in this manner throughout many Third World regions (Singer, 1977).

Although there are many different designs of modern solar grain drying equipment, the basic process involves the passage of sunlight through a glass or plastic plate. Storage bins can then be used to trap the resulting heat, with fans pulling heated air into the bins where the grain is dried. The Brace Institute in Canada has produced many simple low cost, solar drying units of similar designs using indigenous materials. These types of dryers are essentially solar "hot box" which can be used to dehydrate fruits, vegetables and any other products which need to be dehydrated for preservation (U.N., 1980). By drying agricultural products in more protected surroundings, crops can be preserved without exposing them to the wind and rain or insects, rodents and birds. This process is of special interest when drying soft tropical fruits since sugar concentrations increase during the drying process, making the fruit more vulnerable to attack by insects. By adopting such modern drying techniques, Third World regions can reduce waste as well as significantly improve agricultural process control and product.

For fruits and vegetables, sun-drying is the cheapest and simplest way to dry crops in regions having an abundance of solar energy and characterized by low relative humidity and little or no rainfall (U.S. Academy of Sciences, 1979). In the case of green lumber (where direct exposure to the sun tends to produce curling and warping in many woods) in the humid tropics, kilndrying techniques can be applied using solar heated air. Adequate drying of crops can be achieved in humid climates by raising the temperature of the air circulated among the items to be

dried which reduces the relative humidity of the insulated rack box (U.S. Academy of Sciences, 1979).

Although there has been no significant commercial mass manufacture of solar crop dryers, experimentation over the past 20 years has produced a number of designs which are not in use throughout the world. These range from solar heated air dryers in more or less conventional containments to a combination of direct drying and air drying using flat plate collector dryers.[23] Combination solar collector dryers have been designed using indigenous labor and materials (eg. bamboo, old wood, scrap metal and window panes) and successfully introduced in India and Trinidad (Agarival, 1978).

The most economical innovation in solar grain drying are in low temperature, in-storage systems. The storage systems collects solar energy to augment the heat that is normally present in the air, and speeds the drying of grain stored in bins or other shelters. All world regions will be primarily determined by the expected life time of the dryer and related fuel savings, to the life-cycle cost (ie. the total discounted cost of capital).

Recent studies, conducted in the American Midwest have shown that, depending on actual equipment design, 1976 total corn-drying costs ranged

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[23]Flat plate collectors consist of blackened, smooth plates which absorb (both beam and diffuse) solar radiation. On the plate and metal tubing which transfers the heat, absorbed solar energy is converted into an easily transferable form of energy, typically as heated air or water. The second type, the focusing collector, uses a parabolic mirror, reflector mirror or lens to focus the beam component of the incoming radiant energy on a receiver which is actually smaller than the reflector. The result is energy flux which allows collection at higher temperatures. For this system, some degree to allow for changing beam directions is therefore not very efficient in diffuse sunlight (ie. during cloudy periods).

from 10 to 30 cents per bushel using solar dryers. However, about 70 to 80 percent of the total costs represented the fixed costs associated with depreciation, interest, insurance and taxes. Variable costs for solar dryers ranged from 1.5 to 8.4 cents per bushel. By contrast, costs for exhaustible fuel intensive conventional drying (using LP gas, natural gas or electricity) averaged about 15 to 24 cents per bushel, with about 30 to 40 percent of the total in fixed costs and variable costs ranging between 9.0 and 16.8 cents per bushel (Revelle, 1976). Although solar dryers have higher fixed costs, because of minimal fuel and maintenance requirements, the variable costs associated with solar drying systems are considerably lower as compared with conventional dryers. Given appropriate discount rates and development priorities, the use of solar dryers in fuel scarce Third World regions represents a cost competitive way for relatively isolated, rural villagers to preserve valuable agricultural commodities. This helps to minimize waste and spoilage and contributes to increased rural productivity.

Other Passive and Active[24] Uses of Solar Energy

Depending upon the location, energy efficient dwellings can be adapted in ways that makes optimal use of passively entering solar energy (eg. green house, southward facing windows and water heaters) as well as "natural" internal conditioning and insulation (eg. earthbed, trees,

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[24]The passive use of solar energy implies that no "active" mechanical processes (eg. diesel water pumps) are used when collecting and transferring solar heat energy. Active systems typically use solar collectors to capture sunlight and then pump or otherwise mechanically transport the resultant heat (using air water as a medium) to a storage area where it can be tapped as needed.

appropriately sized windows and shutters). The abundance of solar energy in Third World countries experiencing desertification, for example, can be used to promote the construction of reasonably comfortable, energy efficient dwellings which make the best use of the desert environment regardless of how seemingly hostile and uninviting such a climate would be in other circumstances. By optimally matching village dwellings to the local environment, the use of exhaustible fuel intensive processes to stabilize the internal climate of a village dwelling (eg. the use of air conditioners to reduce indoor humidity temperature levels) could be minimized.

The resulting savings associated with reduced fuel requirements could then be used to develop community "site collection areas" (eg. strategically located hydro-electric reservoirs which help keep desert villages cool). Other development projects could include village wide landscaping (eg. community gardens and green houses), windbreaks (eg. forest plantation that are positioned between the village and prevailing wind patterns) and other horti- or silvi-cultural practices which reduce the adverse effects of hot desert winds, dust storms as well as colder seasonal trade winds.

At current prices, solar powered pumps are competitive with fossil fuel (usually diesel) powered pumps only in remote rural areas where fuel and maintenance costs for conventional pumps are prohibitively high. For example, in 1975, a 40-horse power solar pump was designed to meet a Mexican town's irrigation and drinking water needs. Since then, Mexico has ordered ten more such pumps, with Senegal, Niger and Mauritania installing similiar devices (Brown, 1978). Solar energy can be combined with the liquid piston to provide a very simple pump design. When using

this type of pump design, it becomes unnecessary to use water as the working fluid.

Two pumps of a similar design have already been successfully developed and could be easily applied in rural, Third World settings. One such small pump employs a reciprocating piston with the other relying on a small turbine. For liquid piston solar pumps, the vapor must be returned to the boiler (Brown, 1978).

In Bamako, Mali, Daker, Senegal and the Office de L'Energie Solaire du Niger (ONERSOL), solar pumps have been tested and applied successfully in several locations. The pumps tested thus far have been designed as a small, self-contained unit in which the power is locally consumed and not transmitted long distances. In the Saheel, there are already small water pumps in operation which use one kilowatt of solar energy and, with minimum amount of attention and maintenance, can pump from 50 to 80 cubic meters a day, depending on local water tables. It is for these reasons that the Director for ONERSOL has stated that solar pumps have an important role to play in the energy policies of the countries in Saheel where, according to the Director, current conditions for the development and widescale application of various solar energy systems may be the best in the world. Many believe that the cost of the solar pumps could be dramatically reduced by taking advantage of further research findings, especially in the development of solar storage technologies as well as the realization of other economics of production.

Finally, in most rural areas, there is a sound basis in making use of solar powered heat pumps for workable refrigeration systems based on the vapor absorption cycle, particularly for refrigerating milk and other products that may normally deteriorate in storage without refrigeration.

CHAPTER VI

SOLAR THERMAL ENERGY - THE BEST RENEWABLE RESOURCE CANDIDATE - COST BENEFIT ANALYSIS

In contrast to all forms of solar energy technologies discussed in this thesis, solar thermal energy is the best way of harnessing solar energy in the rural Third World.

Considering a typical Third World country like Senegal on the West Coast of Africa, it sounds appropriate to argue that solar thermal energy is the simplest way of harnessing solar energy in the Third World settings. In Senegal, the Office de L'Energie Solaire du Niger (ONERSOL) had tested and applied successfully several forms of the solar technology.

Why Solar?

There are energy alternatives to conventional fossil fuels other than solar energy. However, technologies are limited, underfinanced, and for the most part are not developed for residential dwelling application. While solar technology is primarily focused on individual domestic application, other alternate energy technologies stress a communal contribution, usually for the generation of electricity.

Wind

Wind turbine generators harness the energy of moving air to generate electrical power in some areas of Third World. As offspring of the ancient windmill, these huge rotors can operate within a narrow band of wind

of velocity between eight and sixty miles per hour. Only certain areas of the country can support such wind devices, and these are not on a continual basis. Storage of generated electricity is difficult and expensive. Until many of the economic and performance tradeoffs are determined, wind turbine generators are unlikely to provide a sizeable percentage of energy needs. The possibility does not exist, however, for wind energy to be economically competitive with other sources.

Biomass

The U.S. Department of Energy (DOE) defines biomass as standing vegetation, aquatic crops, forestry and agricultural residues, and animal wastes. Burning wood has been one method of obtaining energy in Senegal and other developing countries for centuries. Biomass is gaining popularity as oil and gas prices rise. However, it is considered not to be unsafe and cannot contribute adequately to the residential energy needs.

Hydro-Power

Water or hydro power as discussed in the preceeding chapter, can be considered as another renewable and "direct" manifestation of solar energy. However, this is limited to just few countries in the Third World due to the lack of large rivers which could be used for such purposes. Moreover, the technologies are limited and it requires millions of foreign exchange to develop hydro electric power in the rural settings. For example, Africa is endowed with 22 percent of all hydro electricity, about half of which is from the Asam High Dam in Egypt, the Akosombo Dam in Ghana, and the Kariba Dam on the Zambezi River between Zambia

and Rhodesia. Senegal and several other countries in the Third World do not have such opportunities. Considering the rural regions, hydro power is unlikely to solve the energy required for rural development.

Nuclear

Nuclear fission and fusion reactors are other sources of energy but they do not appear to be the right source of energy for the rural Third World partly due to the technologies and dangers involved. Fusion requires water as a resource, while fission requires uranium or some other radioactive material, which is depletable. Briefly, nuclear requires a lot of foreign technologies which could not be obtained easily due to security reasons.

Solar Energy

Solar energy has been used by man for hundreds of years, but because of the availability of fossil fuels, primarily oil and gas, solar energy was not widely developed as an energy source. With the 1973 Arab Oil Embargo, Senegal and other less developed countries have realized that oil and gas might not always be available. Enough solar energy or radiation reaches the earth each day "to satisfy man's energy needs."

There are several ways of harnessing solar energy as discussed in this thesis but the simplest is the thermal energy which has advantage over other sources of energy discussed above.

Solar Thermal Energy is the direct heat from the sun which can be captured to perform a variety of tasks. These tasks include domestic water heating, building heating, air conditioning and agricultural crop drying. The utilization of solar energy for agricultural crop drying,

water heating, building heating and cooling can be of major significance, because taken together, these tasks account for nearly half of all the energy currently used in the rural Third World.

Technology

Solar water heating, building space cooling and heating systems presently represent the most technologically advanced and economically attractive solar energy applications. These technologies can be placed into two general categories--passive and active.

Passive solar cooking and heating systems basically consist of highly efficient buildings designed in such a way to minimize heat gains during the warm weathers and heat losses in the cold weathers. Passive systems utilize natural energy flows to transfer heat out and heat into buildings without reliance on the forced circulation of a heating or cooling fluid. These systems often rely on large south-facing windows to increase the gain of solar energy. The insulated shutters mitigate window heat losses during cold nights, whereas reflectors, overhans, and other shading devices diminish unwanted solar radiation during warm weathers. Thermal energy is frequently stored in the building floor, walls and/or ceiling.

In some passive systems, solar collectors, separate from the basic building structure and powered solely by natural convention, provide warm air or water to the space to be heated. In other systems, solar energy is both collected and stored by darkly painted concrete walls or walls composed of blackened, water-bearing drums. Roof ponds can employ water-filled plastic bags installed on the ceiling. Passive solar energy utilization can also be accomplished by green houses designed to permit excess collected heat to migrate into the buildings to which

they are attached. This type of passive system is expected to derive 85 percent of the building energy requirement from the sun.

Active, as opposed to passive, solar cooling and heating systems rely on an external power source for forced transport to distribute energy within the buildings. Special solar collectors and thermal storage reservoirs, apart from the normal heating systems, are employed.

Community scale solar heating systems with centralized annual thermal energy storage hold considerable promise. Centralized storage is attractive owing to its reduced heat losses and cost per unit of stored energy.

Cost Benefit Analysis

The use of any renewable energy resource ultimately depends on the collection and conversion of radiant solar energy into usable forms (whether it is heating space, water or food; drying grains or other crops; photovoltaically co-averting sunlight into electricity, or co-averting indirect sources such as wind, water and plants or biomass into gaseous fuels). As a rule of thumb, the more directly solar energy can be collected and converted into usable form, the greater its "renewability."[25] Thus from the long-run standpoint, it is to the user's advantage to collect, convert and use solar energy in the most technologically direct and least costly manner. In other words, users of solar sources should weigh

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[25]Renewability in this sense, means the degree to which the source of energy maintains its state of entropy regardless of human enterprise. Theoretically, solar emission would remain relatively constant even if future generations were to depend on solar sources for 100 percent of self-renewing sources of energy such as green plants can be affected by human enterprise and thus are not quite as "renewable" as more direct sources of solar energy. This implies that renewable based technologies which rely on self-renewing source of energy may be subject to some supply constraints.

the long-run discounted stream of benefits against the life-cycle costs before actually deciding on which energy conversion technology to develop. Cost benefit analysis might be the best technique for the decision making.

A Theoretical Model: Cost Benefit Analysis on Rural Third World Solar Energy Utilization

The discussion on the theoretical aspects of the cost-benefit analysis in this thesis will be limited to general conceptual description from a system analytical viewpoint, its application on the rural Third World solar energy utilization and economic analysis.

Cost-benefit analysis is a widely accepted method in evaluating investment projects, especially for those involving public funds. To state it briefly: A public projected total benefits must exceed the projected total costs over the lifetime of the project.

Furthermore, in line with the microeconomic theory, using the concept of the Pareto optimally the cost-benefit analysis asserts that for the rural residents harnessing solar energy system, should be at least no worse off, or more positively, better off than the conventional energy system. Then what is the measurement criterion here, the thermal heat replaced by solar energy system or the money saved from the convention energy sources? Maybe both criteria should be considered.

Criteria

The results of a cost-benefit analysis of a potential solar energy harnessing in rural Third World may be given in five items, the net present value, the internal rate of return, the payback period, the years required to positive cash flow and the number of years to recover down payment, each will be described briefly.

Net Present Value

By the discounting process, the net present value (NPV) of the installation of solar system in a rural village house is the sum of the discounted net benefit over the system life. Net benefit used here is the difference between total benefits and total costs of installing a system. Expressing in the mathematical form it is:

$$NPV = \sum_{n=1}^{N} \frac{(Bn - Cn)}{(1+r)^n}$$

Where n = 1, ..., N is the nth year of the total system live N.

r is the discount rate.

Bn is the benefits in n^{th} year.

Cn is the costs in the nth year.

Internal Rate of Return

By definition, the internal rate of return (RT) is the rate of discount that will make the net present value equal to zero, that is:

$$0 = NPV = \sum_{n=1}^{N} \frac{(Bn - Cn)}{(1+IRR)^n}$$

Usually it is obtained by solving this equation using numerical method through large scale computers.

Payback Period

Expressed in terms of the number of years required for cash earnings or savings generated by the new solar system to equal the original investment.

$$PB = t \text{ such that } C_a^t = D^t$$

Where, PB is the payback period at year t,

C_a^t is the cumulative savings at year t,

D^t is the remaining debt at year t.

Years Required to Positive Cash Flow

This is the number of yers needed for the solar system to generate after tax savings to be greater than zero.

$$Y = t \text{ such that } S_a^t = 0$$

Where, Y is the year that leads to positive cash flow.

S_a^t is the after tax savings in year t.

NOTE: This study considers savings in conventional fuel oil as benefits. All other intangible benefits such as psychic value are excluded and not quantified.

Solar Energy Systems Economic Analysis

Using the Cost-Benefit formulas as outlined in this thesis, economic analysis have been made on retrofitting solar energy systems in rural Third World countries, based on several assumptions.

Assumptions

(1) The solar energy systems referred to in the estimation and analysis are feasible with current technology.

(2) The solar energy systems are available to the Third World countries by local construction and or import.

(3) The cost of the system, including equipment, construction, installation and labor.

(4) The measurement criterion here is the dollar saved compared with conventional energy sources - fuel oil.

(5) Third World countries adopting the solar energy systems are favored by geographic locations (thus, they are located in the equatorial zones).

(6) The rural residents in Senegal or any other Third World countries are using fuel oil for drying their agricultural crops.

(7) Finally, it is assumed that the energy equipment for all systems has no salvage value.

Data Sources

The data used for the Cost-Benefit Analysis is based upon the price quotes as exemplified by two firms, the Revere Solar and Architectural Products, Inc., in Kenly, North Carolina, and The Energy Place, Inc. in Greensboro, North Carolina, U.S.A.

Selected Results From the Cost-Benefit Analysis

The empirical findings of the Cost-Benefit Analysis of the potential solar energy harnessing in Senegal are given in five items. These are, the Benefits, the Net Present Value, the Internal Rate of Return, the Payback period and the Years to positive cash flow. This study considers savings in conventional fuel oil as benefits. All other intangible benefits such as psychic values are excluded and not quantified. The discount rate being more or less a subjective operator is selected to be 18 percent in this analysis.

The calculated results are shown in Table 6. Assuming a rural resident in Senegal or any other Third World country is contemplating the

TABLE 6

SOLAR ENERGY SYSTEMS ECONOMIC ANALYSIS
(SOLAR CROP DRYERS)

No	Yrs	Cost of Solar Crop Dryer	Annual Cost of Oil (Benefits for using Solar)	Discount rate (r) %	Benefits (Bn)	NPV	IRR %	Pay back Period	Yrs. to positive cash flow
1	10	$4900	$ 800	18	$3,595.20	$ -1304.80	9	45	46
2	10	4900	820	18	3,685.03	-1214.92	10	46	47
3	10	4900	840	18	3,774.96	-1125.04	11	43	44
4	10	4900	851	18	3,824.39	-1075.61	12	41	42
5	10	4900	900	18	4,044.60	- 855.40	13	23	24
6	10	4900	980	18	4,404.12	- 495.88	15	14	15
7	10	4900	1,000	18	4,494.00	- 405.00	17	13	14
8	10	4900	1,091	18	4,902.95	2.95	18	10	11
9	10	4900	1,200	18	5,392.30	492.80	19	8	9
10	10	4900	1,300	18	5,842.20	942.20	23	7	8

Table 6 Continued

SOLAR ENERGY SYSTEMS ECONOMIC ANALYSIS
(SOLAR CROP DRYERS)

No	Yrs	Cost of Solar Crop Dryer	Annual Cost of Oil (Benefits for using Solar)	Discount rate (r) %	Benefits (Bn)	NPV	IRR %	Pay back Period	Yrs. to positive cash flow
11	10	$4900	$1400	18	$6,291.60	$1,881.60	25	6	6
12	10	4900	1500	18	6,740.00	1,841.00	28	5	6
13	10	4900	1600	18	7,190.40	2,390.40	30	5	6
14	10	4900	1620	18	7,280.28	238.28	31	5.5	6
15	10	4900	1650	18	7,415.10	2,515.10	32	4	4
16	10	4900	1680	18	7,549.92	2,649.92	34	4	5
17	10	4900	1700	18	7,639.80	2,739.80	35	4.5	5
18	10	4900	1800	18	8,089.20	3,189.20	38	3	3
19	10	4900	2000	18	8,988.00	4,088.00	40	2	3
20	10	4900	2100	18	9,437.40	4,537.40	42	2	2

purchase of a solar crop dryer which is capable of drying his crops that he is now drying by using fuel. The solar crop dryer is of a standard size and can generate heat up to 1,912.85 million BTUs per annum. The cost of the new solar system is $4,900 and can be used for ten years.

The rural resident in question spends up to $1,300 annually on fuel oil for drying his crops due to the size of his farm. The cost of the oil is $1.03 per gallon and it would cost $9.41 for the drying oil to generate one million BTUs. Thus, the annual heat load provided using fuel oil is 138.5 million BTUs. The prevailing interest rate (discount rate) is eighteen per cent. Should he purchase the new solar system?

To help the rural dweller to answer this question, it is necessary to isolate the cash inflow and cash outflows associated with the new system. The cash inflow is the $1,300 annual benefit, which is the annual amount he spends on oil. The cash outflow is the $4,900, cost of the solar crop dryer.

In determining whether the dryer is desirable, it is necessary to discount the stream of annual benefit ($1,300) to present value of the dryer. Since the discount rate is 18 percent, this rate is used in the discounting process as shown in case 1 below.

Case	Yrs	Cost of Solar Crop Dryer $	Annual Cost of Oil (Benefits for using solar)	Discount Rate	Benefits Bn	NPV
1	10	$4,900	$1,800	18%	$5,842.20	$942.20
2	10	4,900	900	18%	4,044.60	-855.40

According to the analysis (Case 1 above), the rural dweller should purchase the solar crop dryer. The present value of the cost saving

(Benefit) is $5,842.20, as compared to the present value of only $4,900 for the solar equipment.

Deducting the present value of the investment from the present value of the cost savings gives a net present value (NPV) of $942.20. Whenever the net present value is positive in this analysis, then the solar investment is acceptable, otherwise the investment is not acceptable.

In case 2, as shown above, the annual benefit is $900, using the same discount process as in case 1, the benefits (Bn) turn to be $4,044.60 as compared to the present value of $4,900 for solar system. The net present value (NPV) shows a negative value, (a loss of $855.40), so the solar investment is not acceptable in this case. It should be observed that the only difference in the variables, case 2, such as "number of years," "cost of the solar system," "discount rate" is the "annual benefit" which brought about the vast change in the net present value (NPV).

The internal rate of return, by definition is the rate of discount that will make the net present value equal to zero. In the first case as shown in the table below, the "internal rate of return" (IRR) is 25 percent which is far greater than the given 18 percent. And, the "Payback period" calculated to be seven years while "Years to positive cash flow" is eight years as shown below.

Case	IRR	Payback Period	Yrs. to Positive Cash Flow
1	23	7	8
2	13	23	24

In the second case, the "Internal rate of return" (IRR) is estimated

as 13 percent and the "Payback period" and "Years to positive cash flow" are estimated to be 23 and 24 respectively. Notice the differences in the payback periods of the two cases.

Another estimation shows a very high increase in the "Net Present Value" or $4,537.40 as shown in case 3 below.

Case	Yrs	Cost of Solar Crop Dryer $	Annual Cost of Oil (Benefits for using solar)	Discount Rate	Benefits Bn	NPV
3	10	$4,900	$2,100	18%	$9,437.40	$4,537.40
4	10	4,900	1,600	18%	7,190.40	2,290.40

In case 3, the benefits are estimated to be $9,437.40, almost twice the cost of the solar equipment, and the Net Present Value is $4,537.40. In case 4, the benefits are estimated to be $7,190.40 and the Net Present Value to be $2,290.40. It is interesting to note that those changes in the Net Present Values are caused by the differences in the annual benefits which are the annual expenses on fuel oil.

Notice the differences in the internal rate of return in case 3 and 4 as shown below.

Case	IRR	Payback Period	Yrs. to Positive Cash Flow
3	42	2	2
4	30	5	6

The payback period and years to positive cash flow are the same

(Case 3). In Case 4 the payback period and years to positive cash flow are 5 and 6 respectively.

What matters most in the solar energy decision making, as evident from the analysis, is the annual benefit (which is the amount the individual rural residents spend on drying oil) depending on their farm sizes. Rural residents, who do not spend over $1,000 on drying their crops annually, would not gain by changing to the solar crop drying system. This comparison may provide grounds in explaining why some people are reluctant in the solar equipment at the present time. The reader, however, is reminded to the fact that this comparison is drawn from a set of assumptions, and it should not be considered as conclusive.

On the other, rural residents who spend over $1,000 on fuel oil for drying their crops could definitely gain by purchasing the new solar crop dryer. A large farmer, who spends up to $2,100 on fuel oil for drying their crops could gain over $4,500 as indicated by the Net Present Value in the table.

In summary, the solar energy system has comparative advantage over the conventional fuel system depending upon the user's farm size. When the solar energy resources are explored further, there is possibility of it being 80 percent cheaper than the conventional fuel oil in the years to come. One should not forget that unlike the fuel oil, solar energy is renewable. It would be unfortunate if the Third World ignores it for another decade or two and turn instead to fuel oil.

CONCLUSION

If renewable based technologies are developed and adapted in the Third World village settings, a sound basis for revitalizing rural community life will be established. Furthermore, the incentive for formerly impoverished, rural villagers to migrate into the cities will diminish as increases in rural productivity and higher standards of living are achieved. In fact, many established and well respected international financial and research institutions (eg. The World Bank, Overseas Development Council) have already indicated that the most effective way to slow rural-urban migration and improve rural standards of living for the greatest number of Third World inhabitants is to begin emphasizing rural development.[26]

Since the long-term benefits associated with developing renewable sources of energy, such as improving the quality of village life, are difficult to quantify, such benefits are easily glossed over in many types of economic analysis. The unique capacity of renewable based technologies to provide power in isolated, rural communities, without the need for an elaborate, electrically oriented infrastructure should be considered and incorporated into various types of economic evaluations

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[26]The Third World Bank has defined rural development as "a strategy designed to improve the economic and social well being of a specific group of people; namely, the rural poor." Again, according to the World Bank, "rural development should involve extending the benefits of development to the poorest among those who seek a livelihood in rural areas." This group includes small farmers, tenants and the landless.

(eg. cost/benefit analysis) as various rural development strategies are evaluated.

The development of renewable sources of energy will not only improve the general quality of life, but will allow smaller firms serving the local areas to make use of cleaner, less foreign exchange intensive energy resources. A common criticism associated with the development of small scale, renewable based technologies in rural settings is that they are not able to achieve the same returns to scale that are associated with larger scale, non-renewable based technologies. Although renewable based technologies operate most efficiently on a small scale, the ability for some renewable systems to realize certain returns to scale seems possible, especially in the long-run.

Given that many rural, Third World regions are inhabited by technically uneducated and untrained villagers, technologies designed to raise rural productivity should be simple to make, operate, and maintain. In absence of well developed markets with few resources devoted administration and co-ordination, small firms cannot rely on the market for stream-line "do-it-yourself" organizational systems as do larger industries. Maintenance simplicity is of particular importance in a developing country where mechanics may be few.

The emergence of small, rural industries that manufacture equipment designed specifically to satisfy local energy requirements and basic human needs shows great potential especially in the long-run. Although problems such as the lack of management skills, shortages of capital, technical problems and the lack of expertise can thwart the aspirations of community enterpreneurs, these difficulties can be lessened if "appropriate" technical, administrative and financial assistance can be

provided initially. It would be unfortunate if the Third World ignores it for another decade or two and turn instead to oil. The onset of actual oil shortages together with increasing shortages of traditional energy would force them to begin exploring decentralized renewable energy one or two decades later. In fact, that would put them in deeper trouble than would be the case today.

In order to develop the solar technologies, the relevant energy demand studies carried out for various developing countries should be pooled. "Do-it-yourself" manuals should be prepared in loose leaf form (so that it can be updated as understanding improves). Such a manual should outline how to carry out renewable energy research and how to gather data especially in rural areas.

Solar energy studies should be done on regional basis and there is a need to emphasize rural energy problems. The governments of the Third World countries should allocate enough funds for the development of the solar energy technologies.

The Overseas Development Council (ODC) has proposed establishment of an International Solar Energy Development Fund. This might be financed either through governmental contributions from OECD and OPEC countries as with the International Fund for Agricultural Development (IFAD).

Such funds could be obtained to build solar energy institutes in the Third World countries to train personnel and buy the modern solar equipment. Also such funds could be used to finance and help design field tests of small solar equipment at the village level.

If the foregoing suggestions are taken seriously, a number of countries will want to make the more promising technologies available on a wide scale to villages or market towns throughout their country.

Thermal Solar Energy as discussed in this thesis has advantages over other sources of energy since it is the direct heat from the sun which can be captured and stored to perform a variety of tasks.

The Cost-Benefit Analysis reveals that the solar energy system for drying agricultural crops has comparative advantage over the conventional fuel system depending upon the users' farm sizes.

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