Energy Requirements and Utilization in Rural and Urban Low−Income Settlements

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FOREWORD

Particularly in rural areas, the difficulty of providing energy for human settlements is becoming one of the greatest constraints on the improvement of living conditions. It cannot be expected that the great mass of poor rural people will be able to upgrade their shelter and settlements, unless we can find cheap, practical solutions to the problem of energy supply. For this reason, the International Year of Shelter for the Homeless is vitally concerned with the issue.

This report provides a review of the energy needs of poor settlements, rural and urban, and of some of the avenues to be explored in meeting those needs. It is intended to suggest general guidelines for energy policy which can be considered by the governments of developing countries. It should, however, be seen as part of the over–all effort to upgrade the shelter and settlement conditions of the poor and disadvantaged in developing countries within the framework of the International Year of Shelter for the Homeless.

The technical aspects of most energy solutions are fairly well known, with the small exception of some new technologies still under development. However, there has been a general failure to apply known techniques and adapt them to particular country situations. It is hoped that this report will give some stimulus to the adoption of practical energy programmes for low–income human settlements.

Dr. Arcot Ramachandran
Under–Secretary–General
Executive Director

SUMMARY

Problems of energy and human settlements should be considered on the basis of the short (5–10 years), medium (10–20 years) and long terms (over 20 years). Some of the critical factors which will have to be taken into account are the ecological impact of energy systems, deforestation caused by increases in wood–fuel consumption, energy requirements for food production, economic and social impacts of new technologies in rural settlements, patterns of energy consumption of the urban and rural poor, and capital–intensive and energy–intensive industrialization policies. Experience in many countries indicates that there is a need to plan and implement energy and settlement policies with extensive public participation.

It is necessary to examine new technologies for improved fuel–conversion efficiency. The objectives of introducing innovative energy technologies in human settlements are:

(a) To reduce human labour (especially for women and children engaged in collection of primary energy resources such as fuelwood and vegetable and animal wastes) expended in meeting domestic energy needs and, thus, to improve the quality of life;

(b) To increase the energy base and, hence, productivity in economic development sectors related to human settlements;

(c) To manage production and consumption of non−commercial fuels and increase their conversion efficiencies;

(d) To minimize the impact on the environment of fuel production and use.

The use of non−petroleum energy technologies is particularly relevant to the needs of oil−importing developing countries. In order to shift the energy patterns of an oil−based economy to those of a non−oil−based one and to ensure an adequate and uninterrupted supply of energy to the domestic sector, it is necessary to consider renewable energy resource options, such as solar, wind, biomass, small−scale hydro and decentralized non−oil−based integrated energy systems. At the current level of development, renewable sources of energy probably play a very limited role globally, but their importance at the local level should not be underestimated, and their use should be promoted. Surveys are needed in every developing country to establish the potential of locally available renewable sources of energy which can be harnessed to meet the needs of rural and urban settlements.

A programme for meeting the energy needs of low−income households would include exploiting new energy resources and rationalizing use of commercial fuels. While the technical feasibility of many new energy processes has been established, it is not certain that it will be possible to bring their cost down to levels which will make them economically attractive for large−scale usage. The development and large−scale introduction of an integrated total energy package can only be successfully achieved as part of a national programme, and such an energy programme would have to form part of a subnational development plan, since the varying needs of each region would have to be taken into account, and the technological solutions would have to be adapted and modified to suit local needs.

In view of the escalating cost of energy, the potential for energy conservation should be assessed. The investigation should include:

(a) The potential for energy conservation in heating and cooling existing buildings;

(b) The applicability of bioclimatic design principles in the design of new buildings and planning of new settlements;

(c) The efficiencies of converting fossil fuels into other sources of energy for industry, domestic uses, agriculture and transportation;

(d) The conversion efficiencies of the so−called non−commercial fuels used in domestic, agricultural and small−scale industrial sectors;

(e) The options for energy substitution in performing various functional tasks with a view to conserving non−renewable energy resources;

(f) The potential for improvement of various modes of transportation used in urban and rural settlements.

An integrated approach involving the exploitation of all locally available energy resources would not only optimize the benefits that could be obtained from renewable energy resources but also ensure an uninterrupted supply of energy to meet the needs of the domestic, agricultural and small−scale industrial sectors of rural settlements. In order to establish optimal energy systems, it is desirable to initiate pilot and demonstration projects in a variety of settlement conditions to obtain field data on technological, socio−economic and operational/management problems which must be solved for large−scale application. In order to provide the methodologies for planning human settlements with attention to energy requirements and conservation, it is essential that planning guidelines be developed for various climatic, social and economic environments.

INTRODUCTION

The availability of energy is an important determinant of the quality of life in human settlements. Most countries, in particular, the oil−importing developing countries, have been seriously affected by the current high cost of energy, which has created widespread balance−of−payments difficulties. Although both developed and developing countries have been adversely affected by recent changing energy economics, the force of the impact and the associated problems and issues of energy supply−and−demand patterns have varied from region to region and between and within countries.

The following energy factors have had a crucial impact on recent human settlements development:

(a) The sudden increase in energy prices caught most human settlements unprepared and thus affected the long−term development goals of many communities;

(b) The changing energy situation created complex problems for human settlement planners, most of whom were trained during periods of declining energy prices and have always worked with an implicit assumption of uninterrupted flow of primary energy sources;

(c) Proven technologies for putting to efficient use the primary energy in various sectors of the economy, particularly in the household sector, were unavailable owing in part to a lack of incentives for developing such technologies during the period of declining energy prices;

(d) Technical and economic difficulties interfered with efforts to retro−fit existing buildings and housing stock;

(e) In developing countries with a low technological base, where commercial fuel played a relatively modest role in energy usage, noncommercial fuel accounted for the greatest share of energy consumption but was increasingly scarce, owing, among other factors, to dwindling forest resources.

Conversely, the changing patterns of human settlements have had a significant impact on energy economics. For example:

(a) Current trends in the growth and concentration of population in urban settlements have entailed large expenditures on energy in order to keep the economic sectors viable and to increase productivity and employment;

(b) In developing countries, economic development and improvement in the quality of life of low−income urban and rural settlements have usually resulted in an increase in energy utilization and in the substitution of commercial fuels for non−commercial fuels.

The relationships between energy and human settlements highlight the urgent need to examine both energy and human settlements planning in the context of national development goals. In general, integrated and comprehensive settlement planning or upgrading of existing settlement patterns should mean, among other things, energy economy and efficiency in energy conversion to heat, lighting, power etc. Efforts must be made to evolve appropriate policies, in order to:

(a) Minimize the adverse effects on human settlements that result from fluctuations in energy−supply patterns;

(b) Plan economically viable human settlements based on an appropriate energy mix which minimizes investment and maximizes productivity and employment.

Habitat: United Nations Conference on Human Settlements recognized that human settlements are consuming increasing quantities of energy just when mankind is aware of the need to halt environmentally degrading and wasteful use of non−renewable energy resources. Proper utilization of energy and suitable combinations of energy production processes should be given special consideration in the choice of designs and technologies for human settlements. Those objectives may be achieved by:

(a) Reducing energy consumption by land−use planning, building design, and appropriate transportation systems;

(b) Promoting efficient use of energy resources – for example, through innovative approaches to design and energy management and through incentives for energy conservation or disincentives for wasteful consumption;

(c) Adapting techniques for the production of building materials, for building construction and for the operation of buildings which lower energy requirements, taking into account initial and maintenance costs as well as environmental and social considerations;

(d) Emphasizing the use of renewable over non–renewable energy sources and the rationalization of technologies which are currently known to be hazardous to the environment;

(e) Using energy systems which are less susceptible to power failures over large areas because of disasters;

(f) Developing and implementing small–scale energy conversion, utilization and conservation systems appropriate for meeting the basic energy needs of the rural and urban poor. 1/

The present report deals with various aspects of energy consumption by and energy requirements of the low–income population in urban and rural settlements in developing countries. It also deals with technological options available to meet energy needs in the domestic sector, the potential of renewable energy resources, and institutional and financial issues relating to the utilization of renewable energy resources in developing countries. The emphasis of the report is on the implications of introducing certain energy systems into rural and low–income urban settlements and on policy options for supplying energy needs in the domestic sector.

Chapter I. ENERGY AND HUMAN SETTLEMENTS IN DEVELOPING COUNTRIES

In many developing countries, the living conditions of the majority of the poor have improved very little, especially in rural areas, despite the considerable advances in raising total output during the 1960s and 1970s. This failure to improve the situation of the poor, even in those developing countries where economic growth has been rapid, has led a number of Governments and international agencies to recommend that the prime goal of development should be to meet the basic needs of all sectors of the population.

The process of economic growth is traceable in large part to the substitution of energy for muscle in the performance of every type of agricultural, industrial and domestic task. Moreover, many of the pesticides, herbicides and fertilizers on which successful agriculture in industrialized nations depends are derived from fossil fuel sources. It is hardly surprising, then, that prospects for growth in critical sectors of the less developed economies are linked, at least in part, to the development and exploitation of energy resources available to them.

In many developing countries, economic conditions are such that the bulk of the population is poor and depends mainly on non–commercial fuels. The financial problems of people below the poverty line result in their use of fuelwood and/or cow–dung cake which are the most easily available and cheapest fuels they can get. However, the exploitation of forests and natural fertilizers leads to environmental degradation which reduces the productivity of soil in the long run. Hence, the energy–use patterns increase poverty, and there is a vicious circle which links poverty to energy. In oil–importing countries, oil–based commercial fuels are beyond the reach of not only low–income but even middle–income families.

To understand the magnitude of the problem of economic growth required to satisfy the basic needs of the population in the developing countries, it is instructive to study the demography of those nations.

At the beginning of the last century, the world was perhaps 3 per cent urban, but today urbanization has reached close to 40 per cent. Recent statistics show that the population in cities with at least 1 million inhabitants is growing more rapidly than the total urban population. For instance, the world had only 78 cities of 1 million inhabitants in 1950 compared to 256 in 1985. During those 35 years, the number of cities of that size rose from 47 to 110 in the developed regions and from 31 to 146 in the developing regions of the world. *2/* Approximately one half of the growth in urban population is owing to natural increase and most of the other half to migration from rural to urban areas. The uncontrolled growth of population in the urban areas of developing countries has resulted in an increase of slums and squatter settlements, deterioration and scarcity of housing and the breakdown of infrastructure and services.

The problems of slums and squatter settlements and substandard conditions are not peculiar to urban areas but are also found in rural areas. Despite the accelerated growth in urban population, it is estimated that, by the year 2000, 60 per cent of the developing world's population will still be rural. From table 1, it can be seen that in 1980, approximately 60 per cent of the world's 4,453 million inhabitants were still living in rural areas.

One of the fundamental reasons for rural urban migration is the lack of basic needs such as food, education, health and employment. Energy is a vital determinant in meeting such basic needs. Therefore, in order to raise the quality of life to minimally acceptable levels and to affect trends of rural urban migration, it is essential in rural settlements to provide the necessary energy inputs to increase productivity in agriculture and to establish transportation and communication services.

Patterns of energy consumption in rural settlements

Before the Industrial Revolution, the productivity of a man depended on his own labour and the amount of work he could obtain from domestic animals. The Industrial Revolution led to the rapid application of energy−powered devices which increased productivity. This trend continued through most of this century, resulting in unheard−of records in productivity. However, developing countries that have not yet completed the transition from the agricultural to the industrial stage heavily depend on non−commercial sources of energy. Approximately 90 per cent of the rural energy supply comes from noncommercial energy resources. 3/ So far, very few data are available in developing countries on the consumption patterns of rural energy in various areas such as domestic (cooking, heating and lighting), agriculture, transportation and industry. Information on energy−use patterns is urgently needed in order to assess the energy requirements of rural settlements.

There are many problems in obtaining accurate estimates of noncommercial energy resources. The data so far available for the rural areas of some developing countries suffer from lack of accuracy. Any estimates made so far on the consumption patterns of non−commercial energy resources in rural settlements should therefore be considered at best as approximate and incomplete. However, an analysis of existing data on non−commercial fuel consumption and estimates for future consumption patterns clearly highlights the seriousness of the energy problem in sustaining the present patterns of subsistence in rural settlements.

Table 1. World population distribution by urban and rural category in major areas and regions, 1980

Area or region	Total population (millions)	Urban		Rural	
		Number (millions)	Percentage	Number (millions)	Percentage
World total	4 453	1 776	39.88	2 677	60.12
Developed regions	1 136	802	70.60	334	29.40
Developing regions	3 317	974	29.36	2 343	70.64
Africa	476	137	28.78	339	71.22
Western Africa	144	33	22.92	111	77.08
Eastern Africa	137	21	15.33	115	84.67
Central Africa	55	19	34.54	36	65.46
Northern Africa	108	48	44.44	61	56.56
Southern Africa	33	16	48.48	17	50.52
Asia (excluding the USSR)	2 591	688	26.55	1 902	73.45
East Asia	1 183	331	27.98	852	72.02
Mainland region	1 003	204	20.34	750	79.66
Japan	117	89	76.07	28	23.93
Other East Asia	63	38	60.32	25	39.68
South Asia	1 408	358	25.43	1 051	74.57

Middle South Asia	949	221	23.29	728	76.71
South–eastern Asia	362	86	23.76	276	76.24
South–western Asia	98	51	52.04	47	47.96
Europe (excluding the USSR)	484	344	71.07	140	28.93
Western Europe	153	122	79.74	31	20.26
Southern Europe	139	87	62.58	52	37.41
Eastern Europe	110	65	59.09	45	40.90
Northern Europe	82	70	85.36	12	14.63
Latin America	362	237	65.47	126	34.53
Tropical South America	198	130	65.66	68	34.34
Middle America (mainland)	92	56	60.86	36	39.13
Temperate South America	42	35	83.33	7	16.67
Caribbean	30	16	52.3	14	47.7
North America	252	186	73.81	66	26.19
Oceania	23	17	73.91	6	26.08
Australia and New Zealand	18	15	83.33	3	16.67
Melanesia	4	1	25.00	3	75.00
Polynesia and Micronesia	1	1	50.00	1	50.00
USSR	266	168	63.15	98	36.85

Source: United nations World Population Prospects. Estimates and Projections as assessed in 1982 (United Nations publications, Sales no. 83.XIII.5).

Most of the developing countries are not endowed with commercial fuels such as oil, natural gas and coal. The non–commercial fuels –namely, firewood, charcoal, animal dung cake and vegetable residues –are the primary energy resources used in rural households, agriculture, transportation, small–scale industries, services and construction. The proportion of consumption for domestic use in rural settlements varies from 30 to 70 per cent of the total primary energy consumption. 4/ This is because of the low level of primary energy consumption in agricultural, transportation and industrial sectors.

The rural economy is mostly subsistence–level agrarian, and rural industrial structures tend to be more labour intensive than energy intensive. Hence, it is the domestic use that accounts for the greatest share of primary energy consumption. Table 2, based on available rudimentary data, provides a consolidated picture of various estimates made on rural energy consumption.

The following observations can be made from the table on domestic energy consumption patterns in rural settlements of the developing world:

(a) In Asia, where 69 per cent of the world's population lives, the rural population consumes less than 1 million kilocals (3.4 GJ) per capita per annum in the domestic sector;

(b) In Africa, fuelwood is used for over 90 per cent of primary energy needs, and annual per capita consumption in the rural domestic sector stands at 2.2 million kilocals (9.5 GJ);

(c) In Latin America, primary energy consumption in the domestic sector is substantially higher than in Asia and Africa at 4 million kilocals (18.2 GJ) per capita per annum;

(d) In all regions of the developing world, fuelwood is by far the most important source of primary energy for domestic use in rural areas.

Within Asia, India, Bangladesh, Pakistan and Sri Lanka together account for over 600 million of the rural population. Rural energy consumption patterns for countries in the region are generally similar, owing to similar socio−economic structures. For instance, in the northern region of India, which contained a rural population of over 150 million in 1976, scattered in the plains, hills and desert regions, the energy requirements were met by a variety of fuels, commercial (coal/coke, oil products, electricity) and non−commercial (firewood, dung cake, charcoal, vegetable wastes and muscle power). The patterns of energy consumption are shown in figure 1. The relative importance of commercial and non−commercial fuels with their end use in the household sector are given in figure 2. *5/* It can be seen that the contribution of commercial fuels was only 4.7 per cent, whereas noncommercial fuels accounted for 95.3 per cent.

Table 2. Estimated energy consumption in rural settlements, 1974 (Per capita per year x 10^9 joules)

Region/country	Fuelwood	Residue	Commercial	Total
Asia	3.4			3.4
India	2.4	3.7	0.2	6.3
Bangladesh	2.1	2.5	0.2	4.8
Pakistan	1.5	1.5	0.2	3.2
Indonesia	10.1			10.1
Thailand	6.8			6.8
Africa	9.5			9.5
Sahel region	8.3			8.3
Ethiopia	9.2			9.2
Kenya	10.3			10.3
United Republic of				
Tanzania	24.6			24.6
Uganda	13.6			13.6
Latin America	18.2			18.2
Brazil	31.9			31.9
Colombia	22.7			22.7
Mexico	3.7			3.7
Peru	12.0			12.0

Sources: National Council of Applied Economic Research, "Survey of rural energy consumption in northern India" (New Delhi, 1979);

Jay Dunkerley, "Household energy use and supply by the urban and rural poor in developing countries" (Washington, D.C., Resources for the Future Inc., 1978);

United Nations Secretariat, Department of Economic and Social Affairs, "World energy supplies, 1972−1976", (ST/ESA/STAT/SER.J/21).

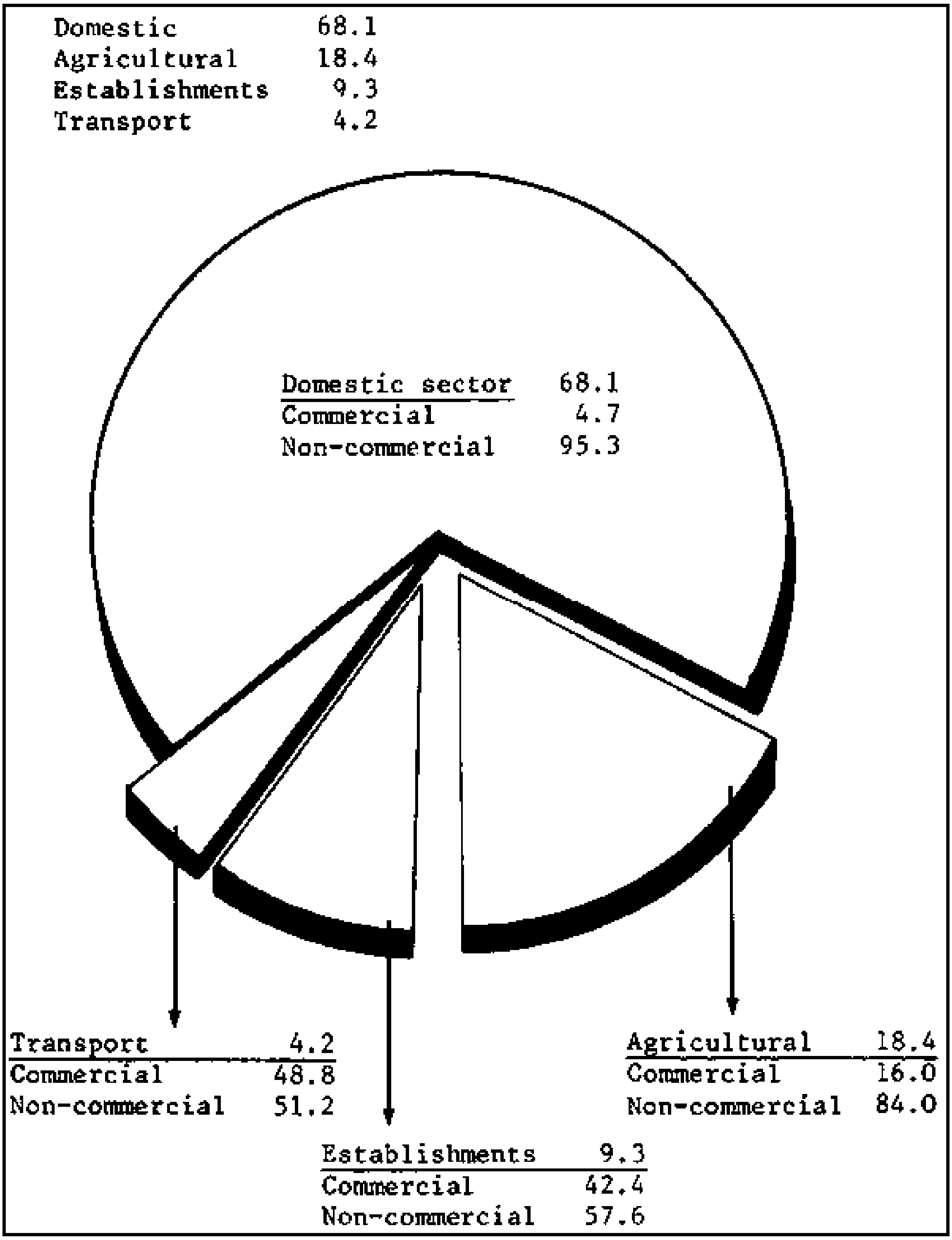

Fig. 1. Sectoral consumption of commercial and non–commercial fuels in rural settlements in northern India, 1975–1976. (All figures are percentages.)

Source: National Council for Applied Economic Research, "Survey of rural energy consumption in northern India" (New Delhi, 1979).

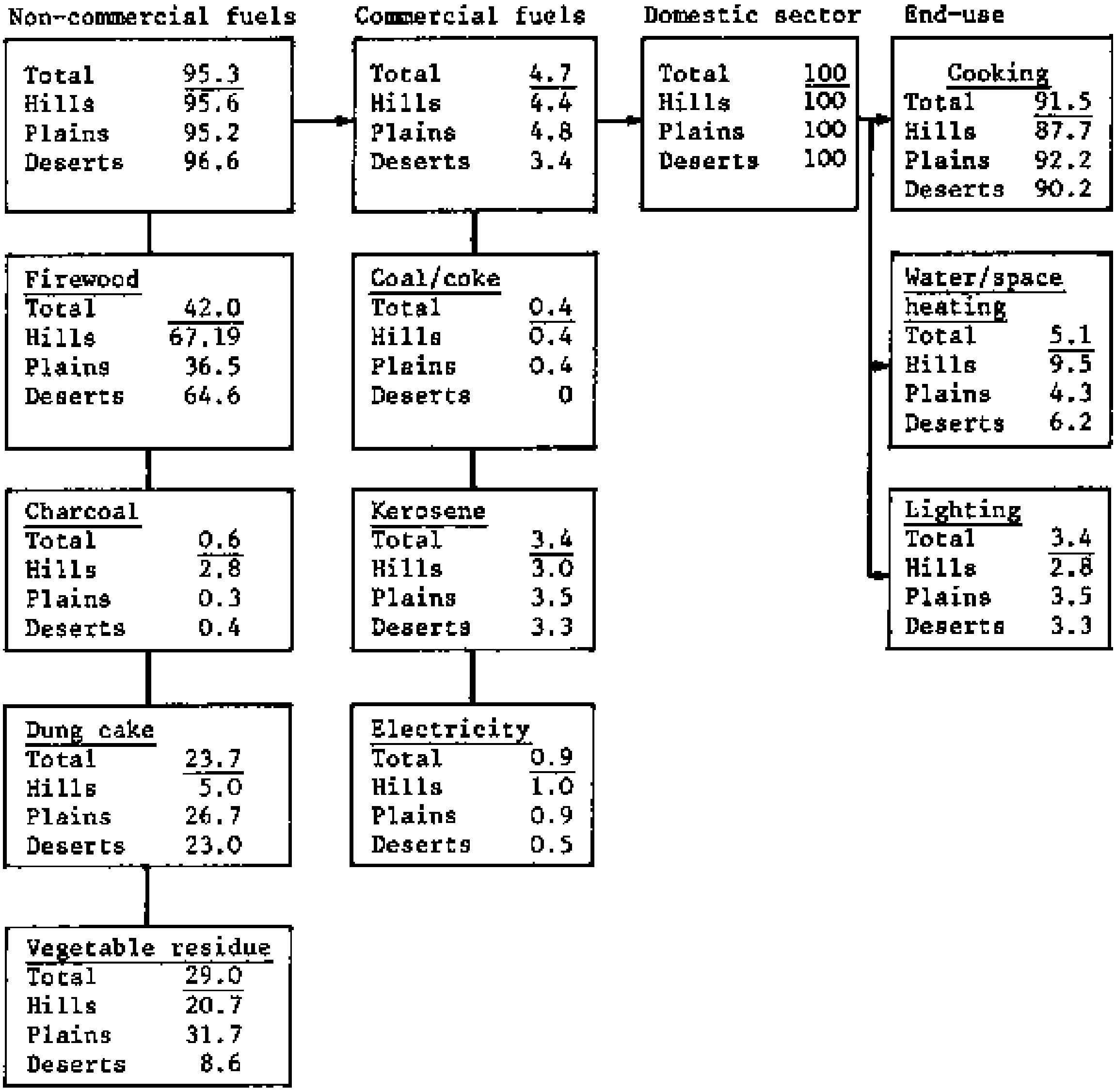

Fig. 2. Proportional breakdown of commercial and non−commercial energy consumption patterns, with the fuel's end uses, in the domestic sector of rural northern India, 1975−1976. (All figures are percentages.)

Source: National Council for Applied Economic Research, "Survey of rural energy consumption in northern India" (New Delhi, 1979).

Among the commercial fuels, kerosene was the main fuel, accounting for 73 per cent of the total commercial fuels used. As for the end use of the fuels, about 91.5 per cent of the total primary fuels were used for cooking, followed by 5.1 per cent for water and space heating, and 3.4 per cent for lighting. More than 90 per cent of the users of firewood, dung cake and coal/coke consumed those fuels for cooking. Among the users of vegetable waste and charcoal, about 80 per cent used those fuels for cooking. Kerosene was used only by 5 per cent of the total households for cooking, mainly in the high−income groups. Only kerosene and electricity were used for lighting, and kerosene accounted for over 92 per cent of households. Firewood and dung cake were the fuels most often used for water heating and space heating.

Table 3 gives the annual average consumption of primary energy resources in northern India per household by end−use and annual income. Several interesting facts emerge from the table. The average consumption per household per annum of non−commercial fuels escalates with increases in income. The same trend was also noticed is respect of commercial fuels. It may be noted that, in all rural settlements, while all the commercial fuels were purchased, 85 per cent of non−commercial fuels were freely obtained from public land. The rate of gathering of non−commercial fuels was uniformly high and was unaffected by level of income. This may be because most members of the high−income groups are landowners, collect fuel from their own farms and consume non−commercial fuels along with commercial fuels.

In Africa, as in Asia, non−commercial fuels account for the greatest share of energy consumption. Fuelwood is used for over 97 per cent of primary energy needs, and kerosene is used for lighting purposes. In Ghana, 6/ for instance, wood is the fuel most widely used for cooking. As shown in table 4, wood is the predominant cooking fuel for 75 per cent of all households and for 93 per cent of households in rural areas. The total consumption of fuelwood (excluding that used for charcoal) increased at an average annual rate of 5.8 per cent between 1966 and 1975, while population grew at an annual rate of about 2.7 per cent over the same period. In Senegal, 7/ firewood and charcoal account for about 60 per cent of the total energy consumed. In Dakar itself, about 85 per cent of household energy requirements are met by charcoal and wood, showing that, in contrast to the situation in other Sahelian countries, charcoal is used in large quantities in the main urban centres. The average fuelwood equivalent consumption in 1979 was estimated at 0.6 cu m (384 kg) per person per annum in rural areas and 0.9 cu m (576 kg) in the urban areas.

There are hardly any data on rural energy consumption patterns among Latin America's 126 million (1980) rural inhabitants, but, from the rudimentary figures available, it appears that wood and other vegetable matter are the main fuels used by most Latin American rural populations. Studies of rural energy consumption patterns in Brazil, Colombia, Mexico and Peru indicate that fuelwood is the main source of primary energy and that the per capita consumption of energy in the domestic sector in rural settlements is almost twice the per capita consumption in Asia or Africa.

Table 3. Relative annual consumption compared to the lowest income group per household of primary energy resources, by end use and by income in northern India, 1977–1978

Fuel/annual income	0–$375	$376–$750	$751–$1 125	Over $ 1 125
Non–commercial				
Firewood	1.0	2.3	2.4	4.0
Dung	1.0	1.5	2.0	2.0
Vegetable residue	1.0	1.9	2.9	3.2
Commercial				
Coal/coke	1.0	3.2	1.0	11.6
Kerosene (cooking)	1.0	9.1	6.1	30.7
Kerosene (lighting)	1.0	1.5	1.9	1.8
Functional use				
Cooking	1.0	2.0	2.4	3.3
Lighting	1.0	1.9	2.1	3.3
Water/space heating	1.0	1.7	2.4	2.6

Source: National Council of Applied Economic Research, "Survey of rural energy consumption in northern India" (New Delhi, 1979).

Table 4. Household cooking fuel in urban and rural areas of Ghana (Percentage)

Predominant fuel used	Rural	areas	Urban	areas	All households	
	1960	1970	1960	1970	1960	1970
Wood	93	93	48	34	80	75
Charcoal	3	5	43	60	15	22
Crop residue	3	2	2	–	3	1
Kerosene	1	–	5	3	2	1
LPG	–	–	1	1	–	1
Electricity	–	–	1	2	–	1

Source: Ghana – Energy Outlook and Options for 1980 (Washington, D.C., World Bank, 1980).

The promotion of rural electrification has been given priority over the past few decades. A World Bank study indicates that, in spite of the interest in and resources committed to rural electrification, only a relatively small portion of villages, generally those located close to central power generating grids, have been electrified. For instance, several studies of the World Bank on rural electrification indicate that only 6 per cent of the villages in Africa, 15 per cent in Asia and 23 per cent in Latin America were electrified.

Despite the availability of electric power in some rural settlements, the per capita consumption of electricity is quite modest. In Latin America, although the overall electric consumption is over 650 kWh per capita per year, only about 2 per cent of the total electricity generated is consumed in the rural areas. In most rural settlements, 50−80 per cent of the consumption of electricity is confined to the commercial and agricultural sectors, and, in the domestic sector, electricity consumption is generally restricted to lighting purposes. Many developing countries have given electrification priority during the past few decades, and some countries have spent as much as 20 per cent of their capital budgets on electrification, with a considerable proportion of the funds going to rural electrification programmes. However, most rural communities are still without electricity, and, in those that do have it, the low income−groups cannot afford it.

The World Bank has been the main advocate of rural electrification, but the policy has not achieved the desired results. Until recently, the Bank promoted the replacement of non−commercial fuels by electricity and oil products. However, their relative costs have changed drastically since 1973/1974, and the World Bank has had to re−examine the role of rural electrification. It now aims to determine the proper role of rural electrification in satisfying rural requirements by establishing the uses for which electricity is economical and socially justified, and investigating the comparative costs of other decentralized systems.

The rural energy consumption patterns of various developing countries indicate the following:

(a) Energy consumption in rural areas is lower than in urban areas;

(b) The relative share of the various primary energy resources in total energy consumption in rural areas is quite different from that in urban areas;

(c) The dominant fuels in rural areas are non−commercial;

(d) The largest portion of the energy supply for the rural poor is secured on the basis of individual or private effort at very low or even zero private cost;

(e) A large proportion of the rural population is very poor and cannot afford to buy commercial fuels.

Given the nature of existing energy consumption patterns and the types of primary energy resources used, the basic tasks involved in formulating a rural energy policy are as follows: 8/

(a) Estimation of the quantities of non−commercial fuels and animal energy used in rural areas for various consumption and production purposes;

(b) Estimation of likely changes in the pattern of rural consumption of different fuels as a result of the growth of agricultural production and improvements in the economic conditions of the rural population;

(c) Identification of the determinants of shifts from noncommercial fuels and animal energy to commercial energy;

(d) Identification of the instruments available to Governments for influencing the pattern of energy utilization in rural areas;

(e) Assessment of the feasibility of meeting the energy needs of rural areas from centralized energy−supply systems and of the extent to which decentralized energy systems can be evolved to cater to those energy needs;

(f) Consideration of the possibility of adopting new energy technologies to supply current and future energy needs.

This implies that the approach to rural energy problems could be based on:

(a) The elucidation of current rural energy consumption patterns and the anticipation of future patterns;

(b) The translation of these patterns into a set of end−uses −e.g., heating, lighting and mechanical work in stationary and mobile equipment;

(c) The consideration of the technologies which can be used for those end−uses in the light of available resources;

(d) The selection of technologies for each category of end−use;

(e) The integration of selected technologies into a system.

Energy consumption patterns of the urban poor

Approximately 40 per cent of the total population of developing countries is expected to live in urban areas by the year 2000, that percentage being 76 per cent for Latin America, 9/ The rapid growth of concentrated populations in urban centres has led to an extreme scarcity of housing, deterioration of living conditions and the breakdown of infrastructure and services, especially transportation, energy supply, water reticulation and health care.

So far, there have been no adequate surveys to examine the basic energy consumption patterns of the urban poor. Since most slum and squatter−settlement dwellers are rural migrants with inadequate resources, they resort, as in rural settlements, to traditional ways of satisfying their energy needs. Firewood and charcoal obtained from the surrounding rural areas are commonly used in the semi−rural squatter settlements located on the outskirts of large urban communities in Africa. Families in squatter communities of large urban centres in Asia have to rely on oil products for their cooking needs, owing to the extremely limited availability of firewood and charcoal. Squatter settlements in South Asia use dried animal wastes, sometimes mixed with coal dust, as a fuel for cooking. Bottled gas and oil products, such as kerosene, are becoming increasingly important among the squatter communities of Asia and Latin Amercia and are primarily used for cooking and lighting. Generally, the use of electricity, where available, is limited to lighting and the running of small appliances.

The annual per capita energy consumption of the urban poor in developing countries does not differ significantly from that of the rural poor, since the main share of energy consumption in both cases goes to cooking. However, with rising incomes, the energy consumption patterns of urban households in developing countries are starting to change. Some examples are given in table 5 which shows that cooking and lighting account practically for all the energy consumed by people in the lowest income group. Appliances and space and water heating account for up to 60 per cent of the energy consumed by the rich in those two cities. With rising incomes, fuelwood tends to be replaced by kerosene and kerosene by gas/electricity for cooking and lighting.

The consumption patterns bring out a common feature of the energy situation in urban communities of developed and developing countries. This is related to the energy consumption patterns of the urban rich who use electricity and gas for operating household appliances, space heating and cooling systems and water heating devices. Planning for their urban settlement needs, therefore, will come up against the global problems of energy conservation (in cooking, heating/cooling, hot−water supply and building) from the points of view of equipment design, pollution and selection of the sources of primary energy.

Almost all the cities of the developing countries are characterized by slums, squatter settlements and other low−income areas which house the majority of urban dwellers. The people living in those areas have energy consumption patterns entirely different from those of the high−income groups. Instead, the energy consumption patterns of such urban areas are very similar to those in rural areas. The heavy dependence of rural populations and urban poor on non−commercial energy sources has several implications. For instance, the exploitation of vegetation cover is leading to serious problems of ecological balance.

Appropriate development models which respond to the needs and aspirations of indigenous populations are required, focusing, among other things, on the provision of basic necessities for the urban poor.

Table 5. Domestic energy consumption per household in 1976 for Mexico City and Nairobi (Percentage)

Functional use			**Annual income**		
	Below $1,000	**$1,000−$2,500**	**$2,500−$5,000**	**$5,000−$10,000**	**Above $10,000**

Mexico City					
Cooking and lighting	52.7	50.5	47.2	34.1	34
Water heating	38.1	28.3	18.9	27.1	30.9
Appliances	9.2	21.1	29.7	34.2	30.7
Heating	–	–	4.2	4.6	4.4
Percentage of total domestic energy consumed	11.7	14.4	16.9	26.6	30.4
Percentage of total transportation energy consumed	1.3	5.8	14.5	30.9	47.5
Nairobi					
Cooking and lighting	100	100	33	33.9	42.7
Water heating	–	–	38.5	39.1	30.6
Appliances	–	–	28.5	27.0	26.7
Percentage of total domestic energy consumed	7.4	7.2	17.8	27.5	40.1
Percentage of total transportation energy consumed	0.5	2.4	12.5	34.6	50.0 r

Source: Cordon McGranahaw and Manuel Taylor, Urban Energy Use Patterns in Developing Countries: Preliminary Studies for Mexico City and Nairobi (Stony Brook, State University of New York, 1978).

Chapter II. ENERGY REQUIREMENTS FOR THE POOR

In developing countries, a great percentage of total energy is used for domestic consumption, approximately 68 per cent in rural areas and approximately 45 per cent in urban areas. 10/ The core issues related to energy for rural areas pertain to the reclaiming and preserving of productive lands, the provision of energy for agriculture and the revitalization of rural life. The dependence of the rural population on fuelwood to satisfy energy requirements has to be reduced so as to reclaim and preserve productive land.

Any adjustment of the trend towards migration to the cities by the rural population can be achieved only by improving rural living conditions through provision of health centres, educational institutions, cultural and entertainment facilities, and employment−generating institutions, apart from communication/transportation systems. All those activities are energy−dependent. Means should, therefore, be provided to tap that energy from all available resources, including new and renewable energy sources.

As to the energy requirements in the urban areas in developing countries, the majority of urban settlements, particularly the main cities, consist of two different and distinct components. Each possesses unique characteristics which reflect the economic and social conditions of its inhabitants. One component follows patterns that are similar to cities in industrialized societies. The energy demands of those areas are similar to those of urban settlements in developed countries and reflect energy consumption patterns of the urban well−to−do, who use electricity, gas and oil for operating and maintaining households and who use energy for commercial buildings, amenities, recreation and transport. Thus, the energy problems in that component of human settlements in developing countries are similar to those found in many developed countries. The other component involves the slums and squatter settlements whose energy−related problems bear a close resemblance to those of the rural population. The energy requirements of the low−income population, whether living in urban squatter settlements or rural areas, can be narrowed down initially to domestic needs. Accordingly, in the present report, domestic energy requirements will be analysed under three headings, namely, cooking and water−heating; lighting; and heating and cooling.

Cooking and water−heating

Domestic energy requirements vary with climate, socio−cultural patterns, family size, cooking habits and the type of food consumed. In general, they may be estimated to range from 5 GJ energy input per capita per year (cooking food on an open fire in warm lowland tropics) to over 25 GJ per capita per year (cooking and heating in cold upland areas), equivalent to 0.5−2.0 cu m. of arid−dried wood fuel per person per year. 11/

Water heating typically accounts for about 5 per cent of the total primary energy consumption, but water heating requirements are seasonal and mainly confined to the high altitudes and high−income groups.

The use of wood for cooking fuel accounts for 50 per cent to 90 per cent of the total primary energy consumed, particularly in the rural settlements of the developing world. More than 70 per cent of the wood in developing countries is used for cooking fuel, and, in some rural settlements, cooking is the only use for wood resources. The patterns of consumption of wood fuels in selected countries are summarized in table 6. In all those countries, fuelwood is used for domestic purposes, and it is the principal fuel for rural households and about 90 per cent of the urban households. The urban use of fuelwood is predominantly in the form of charcoal rather than firewood.

The world consumption of fuelwood and charcoal for 1961−1975 is presented in table 7. It can be seen that the growth rate of fuel−wood consumption was 2 per cent per year between 1961−1975 in the developing world of Africa, Latin America, West Asia and East Asia where the largest percentages of rural population live. Most of the fuelwood used in rural areas is collected by the members of the family, particularly women and children, and until recently collection was confined to areas within walking distance of rural settlements. The progressive destruction of tree and vegetation cover leads not only to a shortage of fuelwood and wood for housing but also to serious ecological consequences such as soil erosion, increasing flood potential, desertification and declining soil fertility. It appears that firewood collection is second only to clearing land for agriculture as a cause for deforestation.

One of the reasons that wood is the preferred domestic fuel is that it does not require a complex and expensive infrastructure to be produced and used as a fuel. Furthermore, thus far it is the cheapest (usually free) available energy resource for the rural population and urban poor. As fuelwood becomes scarce and costly, the poor often resort to the use of animal waste and vegetable refuse which is otherwise used to enrich the soil in order to improve the soil nutrient level, structure and capacity to retain moisture. Woodfuel, vegetable residue and animal wastes (in the form of dried dung cakes) are often used in traditional cooking by burning them on open fires. In order to improve the quality of life in rural settlements and for the urban poor, considerable developmental efforts are needed to improve on traditional cooking methods.

Table 6. The pattern of consumption of woodfuels in selected countries

	Year	Average use of woodfuel per capita/ year (cu. m.)	Charcoal as a share of total wood−fuel use (percentage)	Household use as a share of total wood−fuel use (percentage)	Urban use as a share of total household use (percentage)
Gambia	1973	1.61	26	85	25
India	1970	0.38	–	–	–
Kenya	1960	1.00	6	98	–
Lebanon	1959−1963	0.17	37	98	20
Sudan	1962	1.66	42	98	15
Thailand	1970	1.36	46	91	12
Uganda	1959	1.53	–	92	–
United Republic of Tanzania	1960−1961	1.14	–	97	3
	1968−1969	2.29	3	93	4

Source: J.E.M. Arnold, "Wood energy and rural communities". Natural Resources Forum (3 April 1979).

Table 7. World consumption of fuelwood and charcoal, 1961−1975 (Million m^3 roundwood equivalent)

Area	Consumption				Growth rate 1961−1975
	1961	1965	1970	1975	(percentage per year)
World	1 023	1 084	1 113	1 183	1.0
Developed	138	109	70	56	−6.2
Developing	644	715	788	862	2.1
Centrally planned	241	260	255	265	0.7

Developed	138	109	70	56	−6.2
North America	48	37	19	17	−7.1
Western Europe	69	58	42	33	−5.1
Oceania	4	3	3	3	−2.1
Other	17	11	6	3	−11.7
Developing	644	715	788	862	2.1
Africa	190	208	234	256	2.2
Latin America	186	207	220	226	1.4
West Asia	29	38	39	41	2.5
East Asia	234	258	291	335	2.6
Other	4	4	4	5	1.6
Centrally planned	241	260	255	265	0.7
USSR	98	105	86	83	−1.2
Eastern Europe	16	17	5	14	−0.9
Asia	127	138	154	168	2.0

Note: Figures are rounded.

Source: Food and Agriculture Organization of the United Nations, Yearbook of Forest Products (Rome, 1977).

Assuming average requirements of 0.5−1.0 cu m per capita per year for cooking with a traditional stove (with 5−10 per cent conversion efficiency), about 0.125−0.25 hectares of land is required for wood production, if planted with a tree species producing 20 cu. m. per hectare annually. 12/ In rural settlements, this would mean that the land area needed for fuel plantation would consume from 8−50 per cent of an average family farm of 0.5−3.0 hectares. In order to provide for daily cooking and water heating requirements of the poor, other renewable energy resources should be considered to alleviate the environmental degradation caused by the exploitation of forests.

There is always one section of the urban poor − specifically, those people living in downtown slums away from forests − which cannot get access to fuelwood and dung, and has to utilize commercial fuels for cooking and heating water. Members of that group have been the hardest hit by the energy crisis and by the shortages and increases in prices of oil products, since bottled gas and oil products, such as kerosene, are used by them for cooking and water heating.

The requirements of the rural population and urban poor for cooking and water heating have two aspects: the fuel and the device. The fuel has to be cheap (free, if possible) and easily available, should not cause environmental degradation, should be renewable (if possible), and should not require complicated and expensive infrastructure and devices to produce it and use it. Cooking or water heating devices must be cheap, easily produced with indigenous materials and technology and easily able to meet all the functional requirements for the specific location and customs.

Lighting

The energy requirements for lighting in the domestic sector constitute about 6 per cent of total energy requirements. In rural settlements and to a large extent among the urban poor, the demand for energy as an illuminant arises during the evening hours. Animal and vegetable fats and kerosene are largely used for lighting by the low−income population, and electricity (where available) is used by high−income groups. Past policies on rural electrification programmes did not solve the critical energy problems of the rural population. Some developing countries spent 15−20 per cent of their capital budgets on electrification programmes. However, most villages are still without electricity, and in those that do have it most of the low−income people cannot afford it.

In most developing countries, the typical urban load factor is about 0.5, and the rural load factor varies from 0.10 to 0.25. The load factor, particularly in rural areas, could be increased with the intensification of agriculture through inputs of energy and creation of a rural industrial sector.

Electricity that is produced from fossil fuels must take account of the fact that the conversion efficiency of fossil fuels to electricity is less than 40 per cent, dropping to 25 per cent in some developing countries. An improvement in conversion efficiency is possible through suitable plant design and operation, selection of economical unit−size and efficient maintenance. In some developing countries, transmission losses in carrying electricity from central generating power grids to rural settlements are as high as 20 per cent, which brings about an increase in the unit cost to the end−users in rural settlements. For example, the real cost of supplying one kWh of electricity to rural Kenya is about four times higher than the revenue obtained per kWh.

Table 8 shows how the cost of electricity in India increases with distance from the point of production. In such cases, a decentralized approach to electricity supply for rural settlements can be justified on economical as well as technical grounds. The increasing costs of commercial energy and the inefficient uses of non−commercial energy resources make it imperative to adopt emerging energy technologies for harnessing new and renewable energy sources.

Table 8. Cost of electrical power in India at different distances from the point of production (without taking into account loss of power by transmission)

Distance (km)	US cents per kWh (approximate)	Increase in cost (multiple)
0	2	−
5	5	2.5
10	8	4
20	14	7
40	25	12.5
80	47	23.5

Source: R.L. Datta, "Use of solar cells in India: present and future" Chemical Age of India (April 1977).

Heating and cooling

In many developing countries, such as Afghanistan, India, Iran, Iraq and Turkey, heating requirements are important in the cold season. Even in upland and inland areas near the equator − e.g., in Botswana −heating is a necessity, especially during the night. Where heating is a requirement in rural areas, fuelwood, charcoal, cowdung cake and coal are largely used, whereas, in urban areas, coal, oil products and electricity are used. In areas where heating is needed only at night, the heat from the cooking stove is commonly used for space heating.

It is known that, in many developing countries, approximately 35 per cent of the total energy demand is used in heating and cooling buildings. This unnecessarily high consumption of fuels, especially in urban areas, is caused by buildings not being designed in conformity with bioclimatic design principles.

Chapter III. TECHNOLOGICAL OPTIONS TO MEET ENERGY NEEDS IN THE HUMAN SETTLEMENTS OF DEVELOPING COUNTRIES

Commercial energy sources

In spite of a sharp increase in oil prices with a projected doubling of oil prices in real terms by the year 2000, petroleum products will continue to play a central role in the economic development of most countries. That fact is sometimes lost in the current explosion of interest in alternative sources of energy. For all non−oil−producing developing countries (NODC), consumption of energy was projected to grow by 6.2 per cent per annum during the decade to 17.75 million barrels per day of oil equivalent in 1985 from 9.65 million barrels per day of oil equivalent in 1976. 13/ However, net energy imports of the oil−importing developing countries were projected to rise from 3.2 million barrels per day of oil equivalent in 1976 to 4.3 million barrels per day of oil equivalent in 1985, all in the form of oil.

The World Bank commissioned a survey on the oil and gas situation in 70 developing countries in 1979, and the results of the survey are summarized in table 9. Out of 70 developing countries, 23 have prospects of finding high or very high quantities of petroleum, while a further 15 countries have prospects of locating fair quantities of petroleum. Although the estimates are low as against those for OPEC countries, they are significant in terms of domestic consumption. For instance, most African countries consume less than 5 million barrels a year. The ultimately recoverable reserves of the developing countries are not known with any certainty, but recent estimates suggest that the oil−importing developing countries, whose proven reserves are now about 2 per cent of the world total, could account for about 15 per cent of the world's ultimately recoverable resources. A vigorous effort to improve the available data on the location, scale and commercial exploitability of petroleum reserves is a pre−condition for future increases in production.

Apart from oil exploration, the most immediate and practical activity is the exploration for coal, which can be used as fuel for the generation of thermal electric power and transportation. According to present estimates, coal reserves (including coke, bituminous and sub−bituminous coal as well as lignite) in developing countries are less than 6.5 per cent of the world total. The World Bank information indicates that about 30 developing countries have known but only partially explored coal and lignite reserves. These countries include:

(a) Oil−producing countries such as Algeria, Indonesia, Iran, Nigeria and Venezuela;

(b) Countries with important coal and lignite reserves, some of which are important producers, such as Argentina, Colombia, Egypt, India, Mexico, Turkey, Viet Nam and Yugoslavia;

(c) Countries with medium−sized or relatively inaccessible coal and lignite reserves, such as Afghanistan, Botswana, Burma, Chile, Madagascar, Malawi, Morocco, Mozambique, Pakistan, Peru, Philippines, Somalia, Swaziland, Thailand, United Republic of Tanzania, Zaire and Zambia.

Thus, the problem in most of these countries is not one of identifying new coal fields but one of knowing the extent and quality of existing resources. In the majority of these countries, systematic analyses of the size, quality and mining characteristics of the coal fields have not been sufficiently delineated to allow an economic evaluation of the reserve.

Table 9. Petroleum prospects of 70 developing countries

Type of country	Number of countries	Size of potential resources			
		Very high	High	Fair	Low
Oil producer/net exporter	12	6	3	2	1
Non−producer/known reserves	10	4	2	3	1
Non−producer/no discoveries	45	1	4	10	30
Non−OPEC producer/ exporter	3	2	1	0	0
Total	70	13	10	15	32

Source: World Bank, A Program to Accelerate Petroleum Production in the Developing Countries (Washington, D.C., 1979).

Technological options for renewable energy sources and human settlements

Given the profiles of energy consumption patterns in the rural and urban settlements of the developing world, it is necessary to examine options for introducing new technologies or upgrading existing technologies for improved fuel conversion efficiency. The objectives of introducing new and innovative energy technologies for the general development of human settlements should include the following:

(a) To reduce the human labour and drudgery (especially for the women and children engaged in the collection of primary energy resources such as fuelwood, vegetable and animal wastes) involved in meeting domestic energy needs, and thus to improve the quality of life;

(b) To manage non−commercial fuels efficiently and substantially increase their conversion efficiencies;

(c) To minimize the impact on the environment of current practices of using fuelwood and agricultural wastes;

(d) To increase the energy base with a view to increasing productivity in various economic development sectors.

The use of non−petroleum energy technologies is particularly relevant to the needs of oil−importing developing countries. In order to shift the energy patterns of an oil−based economy to those of a non−oil−based one and to ensure an adequate and uninterrupted supply of energy to the domestic sector, it is necessary to consider renewable energy resource options, such as solar, wind, biomass, small−scale hydro and decentralized non−oil−based integrated energy systems. At the current level of development, renewable sources of energy probably play a very limited role globally, but their importance at the local level should not be underestimated and their use should be promoted. The present state of the art of renewable sources for applications in human settlements may be classified as:

(a) Technologies that are technically viable but are not sufficiently developed for adoption on a wide scale;

(b) Technologies that have been fully developed and tested but are still not being extensively used.

For instance, the use of solar energy in space heating and water heating is sufficiently well developed for application on a wide scale. There should be continuous communication between the scientific and technological community involved in the new, emerging energy technologies and the settlements and development planners in formulating long−range policies based on the dynamic nature of present−day society. An analysis is made here of promising renewable energy systems suitable for use in low−income settlements.

Solar energy

Solar energy is by far the most abundantly available renewable energy resource, particularly in the tropical regions of the developing world. Potential applications of solar energy in human settlements include heating of water, heating and cooling of buildings, refrigeration, water pumping and cooking, electricity generation and desalination of water for domestic consumption. Solar collectors and panels can provide thermal energy for cooking, heating and related tasks. High temperatures can be achieved by using sophisticated devices such as parabolic mirrors and sun−tracking devices. The special applications of solar utilization are analysed below.

Solar cookers

Development of and experimentation with solar cookers have spread during the past several decades, but so far no proven accepted cooker has been developed, partly owing to the availability of cheap fuelwood and charcoal and partly owing to the lack of incentives during the period of declining commercial energy prices before 1974. Basically, solar cookers are of two types: a simple, direct cooker in which the cooking takes place at the point of solar concentration and an advanced cooker consisting of energy storage and sun−tracking devices. Solar collection areas range from 0.36 to 1.07 sq m for solar cookers that have actually been constructed and field−tested.

One way to measure the performance of solar cookers is to compare the effective cooking power in kilowatts. The effective cooking power refers to the rate of energy delivered to the cooking vessel and its contents under clear−sky weather conditions. These values were found to range from 0.15 kW to 0.6 kW. Table 10 gives a summary of the design features of indirect solar cookers tested at the Punjab Agricultural University, in India. 14/ The normal heating time needed to bring one litre of water from ambient temperature to boiling point using a wood fire or a kerosene burner is generally on the order of 5−10 minutes. Table 10 gives comparison times for various designs of focusing solar cookers.

It appears from these investigations that the approximate maximum quantity of food that can be practically cooked on the cookers is from two to four kilograms. Therefore, most of the designs appear to be adequate for cooking simple meals for the average low−income family. As far as the materials required for manufacturing the units locally in developing countries are concerned, all cooker designs need some components or materials manufactured in organized and established industries. For example, the focusing types of solar cookers need plastic film, moulded plastic reflector shells, shaped metal components etc. On the other hand, all those materials could be manufactured in small industrial establishments using local labour and materials.

In order to have stationary operation of an indirect solar cooker during the cooking of food, it is necessary for the cooking time of the food and the frequency of adjustment towards the sun to be reduced.

Table 10. Design features of indirect solar cookers

Design features	Simple box cooker	Box cooker with single reflector	Three-step reflector box cooker	Simple Cone 1	Solar oven 2	Compound Cone 1	Solar Oven 2
Hot box material	Inner and outer rectangular trays made of sheet metal	Inner and outer rectangular trays made of sheet metal	Inner and outer rectangular trays made of sheet metal	Inner and outer semicircular cylindrical boxes made of sheet metal		Inner and outer semicircular cylindrical boxes made of sheet metal	
Insulation	Glass wool (5 cm thick) between the trays	Glass wool (5 cm thick) between the trays	Glass wool (5 cm thick) between the trays	Glass wool (7.5 cm. thick) between the boxes		Glass wool (7.5 cm. thick) between the boxes	
Reflector	None	A plane of glass 50 cm x 50 cm	3 glass mirrors each 25 cm x 75 cm	4 square and 4 triangular mirrors in the form of a simple cone		4 square, 4 rectangular and 8 triangular mirrors in the form of a compound cone	
Window (two glasses 2 cm apart)	50 cm x 50 cm	50 cm x 50 cm	30 cm x 75 cm	37.5 cm x 37.5 cm	37.5 cm x 37.5 cm	30 cm x 37.5 cm	30 cm x 37.5 cm
Concentration ratio (CR)	1	1.29–1.5 depending upon solar altitude	1.9–2.3 depending upon solar altitude	3.1	3.1	3.7	4.5
Ratio of inner loss area/ window area	1.5	1.5	1.59	2.99	4.13	3.21	4.44
Mean depth of inside of hot box a/	9 cm	9 cm	9 cm	16 cm	27 cm	16 cm	27 cm
Time needed to boil 1 litre of water (kept at 10.20 am in July at Ludhiana)		85 min.	55 min.	65 min.	70 min.	55 min.	55 min.

a/ ½ (Inner perimeter of hot box – window width)

That will require a higher concentration ratio of the reflector and a larger acceptance angle than is provided on existing cookers. Those requirements at first appear to be contradictory because, as the concentration ratio of a concentrator is increased, the concentrator needs more frequent adjustments towards the sun, but both the requirements can be easily accommodated in the design of concentrators for indirect solar cookers. For a practical system, designs which yield concentration ratios of between 4 and 5, for stationary operation of about two hours, without using excessive reflecting material can be achieved. Such cookers can collect solar energy at sufficiently high temperature (around 200°C) to cook hard-to-cook foods, such as kidney beans or chickpeas, in two hours.

It was reported that earlier attempts to introduce solar cookers in rural settlements had failed because of such factors as functional use (they work only when sun is shining), expense, and the fact that cooking must be done while the cook stands in the sun. There were no concerted research and development efforts (perhaps owing to competition from cheap commercial energy sources) to design a solar cooker that would provide heat energy at 300°C, suitable for use inside the house, and would have the necessary storage arrangements to deliver heat for a few hours after sundown. In view of the present changing energy situation, it is necessary to undertake a programme to design and construct prototype solar cooking devices using heat transfer systems that would allow cooking to be carried out in a shelter. The principal requirements for the widespread acceptance of solar cookers, particularly in rural settlements, are that the unit must provide heat energy at a sufficient rate and temperature to cook properly desired quantities and types of foods; the unit must be capable of being manufactured with local materials and labour; the unit must be sturdy enough to withstand rough handling; and the unit must be sociologically acceptable.

Solar water pumps

Water is one of the many essentials in short supply in rural and urban settlements, and, in arid and semi−arid regions, rural women often spend long hours collecting water for drinking and cooking. The provision of water for domestic and agricultural consumption is a basic requirement for the general development of rural populations, and solar energy for water pumping has the potential of providing self−sufficiency in water requirements at the village level.

The basic water−pump systems have utilized flat−plate collectors which are very inefficient. The installed costs of solar water pumps have been very high, and it has been estimated that the installed price must be on the order of $1,000−$1,500 per kilowatt before small and medium−sized solar pumps can be economically feasible. Further research and development efforts are therefore needed in order to utilize concentrating collectors to increase the temperature of the working fluid and thus increase the overall efficiency of the system. Assuming that water pumping requirements in rural areas are met by a 2 kW system operating at 10 per cent efficiency, about 20 sq m of collector area are required. That area could be provided by a parabolic dish concentrator of 5 m. in diameter. However, further investigation is needed to determine the economic and technical feasibility of solar−powered water pumps for application in human settlements.

The field of solar photovoltaic water pumping has matured over the past few years to include pumps suitable for a large range of pumping requirements. The pumps are commercially available from a number of manufacturers in the international marketplace. Pumps range from low−lift irrigation pumps designed for a few hectares to large high−volume and deep−well pumps. Pump types range from small immersible pumps to vertical turbine pumps and reciprocating jack pumps for deep wells. 15/

A solar electric pumping system ordinarily consists of a solar cell array to convert solar radiation to electric power, a control system and an electric pump. Battery storage is usually not used because the economics show that storing water in tanks is more cost−effective than storing electricity in batteries. However, where pumping is not required every day, the inclusion of batteries in a pump system can reduce the system cost by using fewer solar cell modules and pumping infrequently.

The solar size is dependent on the amount of energy required to lift the desired quantity of water through the required head. To achieve maximum efficiency, pumps, electric motors and control systems must be carefully designed and matched. Standard well−matched systems are now available from manufacturers. 16/

In remote areas where transport, fuel and maintenance costs are high and there is sufficient solar intensity, solar pumps are a cost−effective option. Solar−powered pumps can open new areas to agricultural development and supply domestic drinking water to places far removed from the electrical grid and from conventional fuel supplies. Moreover, for small loads off the electrical grid where diesel or petrol generators are the only alternative, they compete well when costed over system lifetimes. 17/

Insolation must be high, with a minimum of cloudy days during the year. Direct sun produces the maximum power, but approximately one−third direct sunpower is available on most cloudy days. Where continuous power is required, battery storage can be utilized to provide power at night and during cloudy periods. Dust accumulation reduces the power available from solar cell modules, and very dusty locations must be avoided since otherwise very frequent cleaning will be required.

Costs for solar pumping systems (as for conventional systems) are dependent on required head and flow. Since the solar cell array is the main cost item, the power required to lift the desired quantity of water from the source determines the cost Solar cells are a quiet means of energy conversion and have long service lives with practically no maintenance (other than cleaning). Many of the motors are of a brushless type with good bearings. Pumps are chosen to match the motors and to last as long as possible with no maintenance. Transport costs are reduced because of the very light weight of the solar cells as compared to a diesel engine.

Solar water heating

Using solar energy for heating water to provide domestic hot water supply has been tried successfully. The solar systems, in most cases, are often found to be economically competitive with those using fossil fuel, and several countries have used solar water heaters for many years. For instance, in Australia, there is now an established industry which produces about 1.5 million units per year. In some districts, particularly in northern Australia, domestic water is heated by using solar energy alone. In Cyprus, solar water heaters are used exclusively to supply hot water for domestic purposes, with each unit having 2.4 sq m of collector area, and manufacturers are currently producing over 7,000 units per year. In Japan, thousands of solar water heaters have been manufactured with a design that combines the collector and storage functions to produce hot water for use at the end of the day.

The thermosyphon water heater can be installed to give continuous and automatic service – i.e., as hot water is drawn, cold water is added to the storage tank to replace the volume. The arrangement involves additional plumbing and an additional tank, apart from the requirement of assured water supply throughout the day.

A storage−cum−collector type water heater is designed to be filled with cold water in the morning and to be emptied about one hour before sunset. During the night, the heated water is stored in an insulated tank of the type used as a storage tank in the thermosyphon water heater. The insulated tank is normally placed near the place of use of the hot water. The water heater has been designed so that it can be filled by the water supply system or by buckets. Filling and emptying the heater is done manually.

The cost of solar water heaters varies considerably with the quality of construction and the materials used. The solar water heaters used in Japan, with collector and storage facilities, were sold for approximately $100−$150. In the United States of America, a family−sized solar water−heater, with a collection area of 3 sq m and 200 litres storage capacity, costs approximately $300. 18/ Domestic consumption of hot water is generally predominant in high−income groups, and electricity and fossil fuels are the most common forms of energy used in water heating. In view of the current maturity of solar water heater technology, the use of domestic solar water heaters should be promoted by providing appropriate incentives to houseowners. The materials and fabrication of solar water heaters currently used in the developed countries could be adapted to the developing countries using indigenous materials and labour.

While it is true that solar water heaters are commercially available in almost all countries, the performance and durability characteristics differ. It is thus desirable that:

(a) National standards and testing procedures giving accurate data on collection efficiency should be developed, without precluding the development of regional standards;

(b) Because of the varying meteorological conditions to which collectors can be exposed and the subtle effects of test conditions, national testing centres for testing solar collectors should be established;

(c) Continuing work on improving standards and testing procedures should be undertaken;

(d) National efforts should be made to develop inexpensive, efficient and durable materials for covers, absorber plates, insulation, housing, surface coating and associated systems hardware, as required.

Solar distillation of water

Water−related problems, such as the shortage of potable water, prevalence of water−borne diseases and difficulties of disposal of sanitary wastes and maintenance of hygiene, have promoted many national and international development agencies to put the provision of clean water at the top of their lists of development priorities. Solar distillation of water is an important alternative for water treatment in sunny, remote areas, where conventional fuels, water treatment chemicals and operating and maintenance expertise are expensive.

In areas where high−density settlements have grown rapidly and exceeded the capacity of the installed infrastructure, water supplies tend to become polluted. In some high−production agricultural areas, water supplies are polluted with chemicals beyond the purification capability of simple treatment plants. When only saline water is available, coastal areas and islands often spend a great deal of government revenue to import or pipe in fresh water. Water is sufficiently valuable in some very arid areas to warrant the reuse of sullage and grey water. With the looming crisis in supplies of wood and other fuels for boiling and treating water for human consumption and domestic utilization, solar distillation technology is an effective alternative for water treatment.

Utilization of solar distillation plants in water treatment has increased dramatically in recent years. In 1980, there were 2,200 solar distillation plants with a capacity of 100 cu m or more per day. Those plants produced a total of 8 million cu m of fresh water per day using conventional fuels; 2.4 million cu m of that total capacity is located in Saudi Arabia.

The simple basin type of solar still, as used in a mining community in Las Salinas, Chile, from 1872 to 1912 with uninterrupted service and little maintenance, continues to be the most effective device for solar water distillation in remote developing areas, 19, 20/ With an area of 45 sq m, the Las Salinas plant purifies approximately 22,500 litres per day. The materials used were glass and wood. In settlements with serious water−treatment problems, the basin still is a water treatment alternative for plant sizes less than 200 cu m per day (according to a 1970 feasibility study).

The theory and the operation of solar basin stills are relatively easy to understand. A shallow basin of unpotable water is covered with a sheet of glass inclined at about 20°. Solar energy is absorbed in the water, the temperature of the water rises, and the water evaporates, condenses, forms on the cover glass and trickles down the glass into a collection trough. All of the pathogens, inorganic salts, pollutants etc. are left in the brine basin. A regular wash−out procedure prevents precipitation of difficult−to−clean deposits in the supply basin.

A few alternate designs have been proposed. They include multiple−step or tilted solar stills, flash evaporation solar stills and multiple−effect solar stills.

The tilted type of solar still has the advantages of very shallow water, reduced side loss and − most important − optimum orientation with respect to incoming solar radiation. The last factor increases both the solar input and the efficiency of the still. The productivity during the winter months in high latitudes may be increased significantly by changing the orientation. The tilted type of solar still has been made in small sizes only. They perform more efficiently than basin−type solar stills but are expensive to construct and maintain. A wick type of unit worked satisfactorily for a short time but it was extremely difficult to keep the wicks uniformly wet.

Some preliminary studies regarding the economics of solar flash evaporation have been carried out. The production of water vapour by the sudden release of pressure on hot water that is near its boiling point is known as flash evaporation. The hot brine provided from a solar heating device is fed into a multi−stage flash distillation plant. The system uses a circulating pump and a vacuum pump and is only suitable where land costs are high and electricity is available. The economics of the solar flash evaporation system have been calculated as only slightly (7−15 per cent) better than those of the basin system, under conditions in India.

The development of high−performance medium−temperature flat−plate collectors and of stationary concentrators that can produce heat at 100−150°C with reasonable efficiency enhances the chances of use of multiple−effect solar stills. It might be possible to separate the collection of solar energy and the distilling of brine in a multiple−effect solar still, but this aspect of solar distillation needs further investigation.

Multiple−purpose processes, producing a combination of products, such as water and salt, and using a greenhouse as a collector/distiller and for growing plants, offer promise in those unique situations where a combination of appropriately related needs exists. A solar pond could produce both salt and water. Similarly, a large greenhouse could be used as a collector/distiller and for growing plants, with the evaporated and transpired water vapour recondensed on the cover of the greenhouse. The combination would require a much smaller supply of distillate than if there were a separate distilling plant supplying water for open plant growth. The still provides an additional function at a small cost and increases economic viability.

In very remote areas with saline or brackish water supplies, distilled water has many important special applications. Distilled water can be used in batteries, engine (automotive and stationary) cooling systems and medical clinics. The medical uses include special feeding liquids (e.g., glucose), laboratory use, surgical cleaning, pharmaceutical preparation and infusion fluids.

Solar distillation is the most cost−effective solution in very remote areas with high solar intensities and few cloudy days. In those areas, fuel supplies and skilled operating and maintenance expertise can be very expensive for conventional water−treatment facilities. Some factors to be considered in determining the feasibility of solar distillation as a water treatment option 21/ include the follwing:

(a) The land area requirements are approximately 0.25 sq m for each litre of water per day in output − therefore, there is need for large areas;

(b) Since the output is directly related to insolation, operation is most favourable where insolation is high and there are few cloudy days per year without rainfall;

(c) Feed–water supply should be close to the plant site to avoid pumping costs;

(d) Although solar distillation plants can be built in practically any size, an output of 200 cu m per day is usually suggested as the point at which other treatment techniques become less expensive in remote locations;

(e) If expertise for plant operation and maintenance is not available in the community, solar distillation is favoured, because of the simplicity of the systems;

(f) If the types of impurities to be removed (e.g., pesticides and other agricultural pollutants) cannot be eliminated by standard filtration techniques, solar distillation is an excellent option;

(g) The availability and cost of glass or transparent plastic sheets will most likely determine the cost of the plant, since they are the main imported items.

Plant construction costs vary considerably. Costed over a 10–year operating life, a nominal plant construction cost of $27 per sq. m. translates into a potable water treatment cost of approximately $2.50 per thousand litres. The most recent figures available on solar distillation plant costs come from one of the principal institutions involved in solar distillation research and development, the Brace Research Institute in Montreal, Canada. To supply the fresh water requirements of Punta Canoa, Colombia, a village of 600 people, the Institute assisted in the design of a 400 sq. m. solar still. Production is 1,500 litres per day for an installation cost of $30,000 Canadian. This cost includes the glass–covered distillation basins, a shallow well dug nearby, a wind pump, a standby hand pump and the fresh–water storage tanks. The following results are obtained: yield 3.75 litres per sq m; cost $75 per sq m; cost/person – $50.

Solar electricity

Solar energy converted into electricity is particularly suited to isolated rural communities. Basically, there are two types of technology: conversion of solar radiation into heat and then into electricity in a thermodynamic process; and direct conversion by transfer of radiant energy. Thermodynamic power generators based on solar energy have been used in a number of power plants in the power range above 1 kW. Heat energy is collected by the absorbers from solar radiation and converted into mechanical or electrical energy by turbine or piston engines. The flat–plate collectors provide operating conditions at less than 100°C, and the efficiencies of conversion are less than 5 per cent. Low concentrating systems (e.g., strip mirror collectors, parabolic trough mirrors, Fresnel mirrors) usually provide higher operating conditions of over 300°C. 22/ Since the solar thermal plants use direct solar radiation, the problem of storage (thermal or electrical) should be considered for application in rural areas. Although solar thermal power plants in the 10 kW range have potential for application in rural settlements, the economic advantage of solar thermal power generation has not been clearly established.

Systems standardization and low manufacturing costs are perhaps the most important aspects for promoting this technology in rural areas. The current cost of solar thermal electric systems is around $8,000 per kW for systems of capacities from 10 to 100 kW, and the future economic viability of solar thermal plants will largely depend upon the escalating costs of conventional fuels and the recognition of environmental costs associated with conventional power production.

Solar radiation can be directly converted into electricity by solar cells. The most popular ones are silicon solar cells which are arranged in units, each capable of generating 1 kW. Direct conversion of solar energy to electricity by means of photovoltaic devices is perhaps the simplest process, because photovoltaic systems have high reliability, low maintenance requirements, no fuel costs, modularity (when one piece of the system goes out, the rest can continue to function), intermittent output without storage, and continuous output with storage, and continuous output with storage. The disadvantages of solar cells are their low conversion efficiency and the fact that thermal storage cannot be used. Considerable research and development efforts are needed to prove their reliability under different climatic conditions before they can be economically competitive with conventional electricity generation.

The operation of the solar cell is based on the photovoltaic effect – the creation of charge carriers within a material by the absorption of energy from incident ionizing radiation. The materials within which this occurs most usefully are the semiconductors – those whose properties are somewhere between those of conductors and insulators. They are characterized by the fact that their valence electrons are not free to move about and conduct current, as is the case in metals, but are normally confined to electron−pair bonds between the atoms in the crystal. In semiconductors, however, the band of energy levels normally occupied by valence electrons is sufficiently close to the band of energy levels available to conduction electrons that, by absorbing the energy of a photon, an electron can jump the gap between the valence band and the conduction band and become a carrier of electric current. The resultant vacancy ("hole) created in the residual electron−pair bond can be filled by an electron from a neighbouring bond, which has the effect of a positive charge or "hole" migrating in a direction opposite to that of the electron flow.

In order for the conduction of electricity made possible by the creation of hole−electron pairs by ionizing radiation to perform useful work, three conditions must be met. First, the number of pairs of charge carriers created must exceed the number normally present at a given temperature. Secondly, the material must contain an internal inhomogeneity that keeps opposite charges separate until they are permitted to recombine by flowing through an external circuit. Thirdly, the mean diffusion distance (lifetime) for holes and electrons before they recombine must be greater than the distance to the "collection point", i.e., the inhomogeneity.

Literally dozens of materials, alone or in combination, possess the semiconductor properties required for high−efficiency (>10) conversion of solar radiation to electricity. A number of them have been investigated as possible commercial solar−cell materials, and three of them − silicon, cadmium sulfide and gallium arsenide −have all been successfully used in spacecraft applications. Others are in experimental stages of investigation. Still others, though known theoretically to be potentially interesting candidates, have yet to be thoroughly studied.

Photovoltaic systems with 10 per cent conversion efficiency and with peak−power capacities from 1 watt to tens of kilowatts are available from manufacturers in several developed countries. The current price for individual silicon solar cells is approximately $10,000 per kW. Several development methods are currently under investigation to reduce the cost of silicon cells and bring it down to below $1,000 per kW in the near future.

The cost of supplying electrical power through solar cells in the United Republic of Tanzania was based on a solar cell cost of $20 per peak watt. A solar array (group of solar cell modules) with a peak power capacity of 1 kW will produce an average 5.3 kWh daily under the United Republic of Tanzania solar conditions. The estimated cost per kWh was in the order of $1.33, which is approximately 12 times the average cost in 1977 of grid electricity in Dar−es−Salaam. 23/ If the present interest and present resources committed for research into and development of solar cells are sustained, it may be possible to make them available at much reduced cost with mass−scale production.

Communications

In the extension of communication services to rural areas, the provision of reliable sources of power is a large cost element. The development of solid−state equipment has improved operating efficiencies but has not solved the problem. Rural switching centres for 50−300 telephone lines require 250−400 watts of electrical power, and radio telephone systems have power requirements in the same range.

The reliability of solar cells is well established in the telecommunications field. They have been used to power communications satellites for many years. Photovoltaic systems are the lowest−cost option for power requirements of less than 400 watts.

Diesel generator sets are not cost−effective for small loads, because it is not practical to build them small enough. The graph in figure 3 shows the dependence of the cost per kW generated on the power factor (the amount of power used divided by the capacity of the generator). As shown in the graph, production costs rise rapidly for power factors less than 70 per cent. 24/ Generators are available in sizes as small as a few kW but they are still very inefficient for loads less than 1 kW. In that range, photovoltaic electrical systems are very competitive, when operating costs and maintenance costs are considered.

Biogas

The annual primary photosynthetic production of the world's forests is over 50 tera watts (1 TW = 10^{12} watts), approximately 10 times that of the total annual present production of oil and natural gas. At present, in most of the rural and urban settlements of the developing world, organic matter, such as agricultural residues and animal wastes, is improperly utilized by burning it inefficiently to obtain heat energy. A range of technological possibilities exists for converting agricultural residues and animal wastes to useful high−energy fuels such as methane, hydrogen, oils and alcohol. Some of the technological options for conversion of organic matter are shown in figure 4. The options shown are not all feasible or practical for all socio−economic and cultural conditions, but, given a potential feed−stock for conversion and knowledge of the characteristics of settlements patterns, it would not be difficult to establish a range of potentially feasible techniques for efficient conversion of organic matter into useful fuels for the domestic sector.

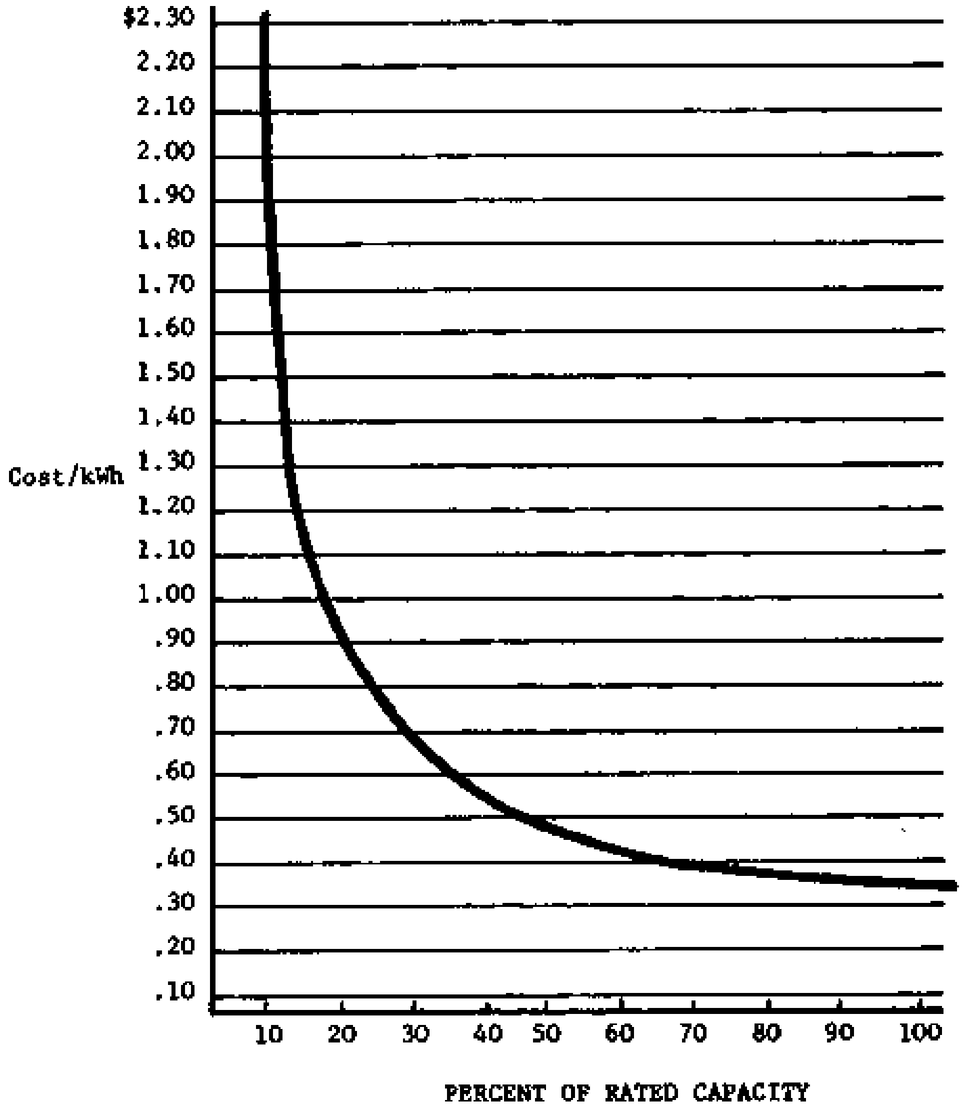

Fig. 3. Variation of cost per kilowatt with power factor for a 8 kWH diesel generator (cost of fuel, $ 1.50 per gallon).

Source: T.D. Paul, How to Design an Independent Power System, (Necedah, Wisconsin, Best Energy Sytems Inc., 1979).

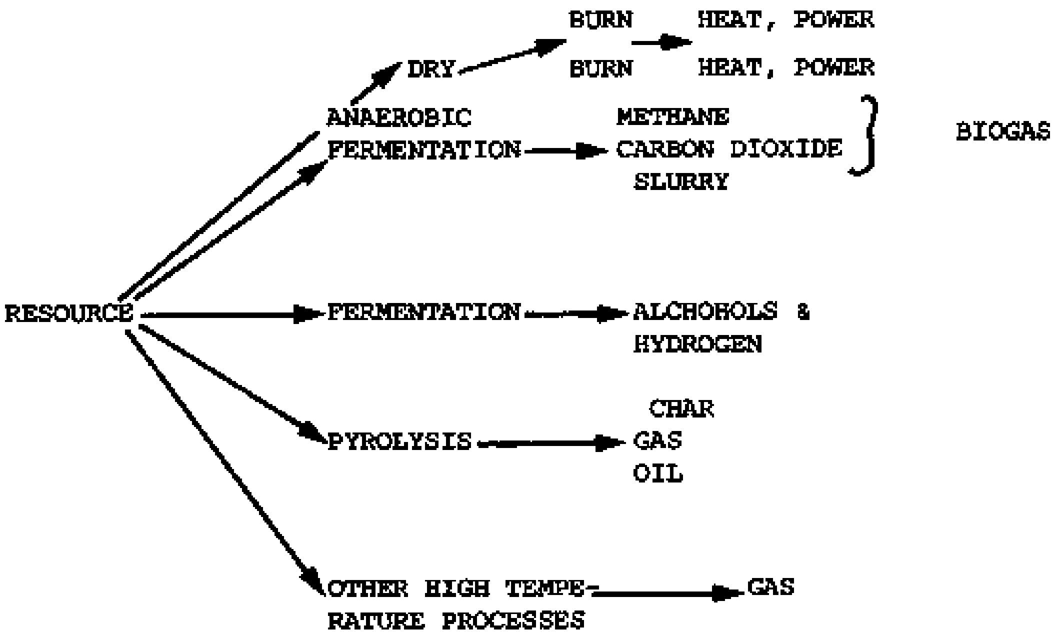

Figure 4. Technological options for converting organic matter into energy.

Source: Report of the Group Meeting on Alternative Energy Sources, 18−22 September 1977 (London, Commonwealth Scientific Council).

In a biogas plant, organic material mixed with water is allowed to ferment anaerobically – i.e., in the absence of air and oxygen −and, during the fermentation process, a gas composed of 50−70 per cent methane is generated. The production of methane during the anaerobic digestion of biologically degradable organic matter depends on the amount and kind of material added to the system, but about 0.5−0.6 cu m of gas (containing 50−70 per cent metnane) can be produced per kg. of dry, highly biodegradable matter added to the biogas digester. The combustion of 50 litres of gas will release an amount of energy equivalent to that required to light a 25−watt bulb for about six hours. In rural settlements, the important consideration for biogas generation is the quantity and quality of the available agricultural residues and animal wastes which can be used as energy food−stock. Table 11 lists various organic materials available in rural areas which have potential for biogas generation. The biogas produced from the organic materials is colourless and flammable, and contains approximately 60 per cent methane and 40 per cent carbon dioxide. The gas has a calorific value of more than 18,000 kJ/cu m. Various investigations have been carried out on the quantity and composition of the biogas produced from different organic materials, and the results of those investigations are summarized in table 12. The amount of gas (methane) produced by anaerobic fermentation depends primarily on the nature of the raw organic materials, the temperature and the period of digestion. It has been observed that gas production is greater at higher temperatures.

Table 11. Organic matter with potential for methane generation

Crop wastes	Sugarcane trash, weeds, corn and related crop stubble, straw, spoiled fodder
Wastes of animal origin	Cattle−shed wastes (dung, urine, litter), poultry litter, sheep and goat droppings, slaughterhouse wastes (blood, meat), fishery wastes, leather, wool wastes
Wastes of human origin	Faeces, urine, refuse
Byproducts and wastes from agriculture−based industries	Oil cakes, bagasse, rice bran, tobacco wastes and seeds, wastes from fruit and vegetable processing, press−mud from sugar factories, tea waste, cotton dust from textile industries
Forest litter	Twigs, bark, branches, leaves
Wastes from aquatic growth	Marine algae, seaweeds, water hyacinths

Table 12. Yield of biogas from various organic materials a/

Raw material	Biogas production per unit weight of dry solids (m^3/kg)	Temperature (°C)	Ch_4 content in gas (percentage)	Fermentation time (days)
Cow dung	0.33	–	–	–

Cattle manure	0.31	–	–	–
Cattle manure (India)	0.23–0.50	11.1–31.1	–	–
Cattle manure (Federal				
Republic of Germany)	0.20–0.29	15.5–17.3	–	–
Beef manure	0.86 b/	34.6	58	10
Beef manure	1.11	34.6	57	10
Chicken manure	0.31 c/	37.3	60	30
Poultry manure	0.46–0.54 d/	32.6	58	10–15
Poultry manure	0.56 d/	50.6	69	9
Swine manure e/ f/	0.69–0.76	32.6	58–60	10–15
Swine manure e/ f/	0.49	32.9	61	10
Swine manure	1.02	34.6	68	20
Sheep manure e/	0.37–0.61	–	64	20
Forage leaves	0.5	–	–	29
Sugar beet leaves	0.5	–	–	14
Algae	0.32	45–50	–	11–20
Night soil	0.38	20–26.2	–	21

Source: Methane Generation from Human, Animal and Agricultural Wastes (Washington, D.C., National Academy of Sciencies, 1977).

a/ Some figures have been rounded to the nearest tenth.

b/ Based on total solids.

c/ Based on volatile solids fed.

d/ Based on volatile solids destroyed. These results may be expressed as 4.0–4.7 ft^3/lb dry solids added, or 0.26–0.30 m3/kg.

e/ Includes both faeces and urine.

f/ Animals on growing and finishing rations.

Among the many potential uses of biogas in the domestic sector are hot–water heating, space heating, lighting and cooking (table 13). Digester gas can also be used in commercially available gas–burning appliances with suitable modification. Conversion of internal–combustion engines to run on digester gas can be relatively simple, and thus the gas can be used for water pumping and the generation of electricity. The consumption rates of gas in various domestic appliances are given in table 14. Technology for the production of required quantities of biogas for consumption in the domestic sector of rural settlements is known and reliable, particularly where livestock is abundant. In addition to the gas generated by the digestion of organic materials, the residue of undigested materials which leaves the biogas plant is an excellent fertilizer and does not attract flies which spread disease. A comparison of manure obtained from organic materials by the traditional methods and through the biogas plant is given in table 15. It can be seen that there is an increase in the final amount of manure and that it has enriched nitrogen content.

Table 13. Heating equivalents of 1 m^3 biogas

Kerosene	0.62 ?
Firewood	3.5 kg

Charcoal	1.5 kg
Cow dung	12.3 kg
LPG	0.43 kg
Electricity	4.7 kWh
Petrol	0.4 ?
Diesel	0.59 ?

Source: Seminar on Alternative Energy Resources and their Potential in Rural Development, Sri Lanka, 2 December 1976, "Notes on biogas" (annex I), (Commonwealth Science Council), CSC (76) S−2.

Table 14. Biogas consumption (approximate)

Cooking	0.5 m^3/hr
Light	0.1 m^3/hr
Engine power	0.5 m^3/horse power

Source; Seminar on Alternative Energy Resources and their Potential in Rural Development, Sri Lanka, 2 December 1976, "Notes on biogas" (annex I), (Commonwealth Science Council), CSC (76) S−2.

Table 15. Comparison of manure obtained by traditional methods and through a biogas plant (fresh dung, 1,000 kg (0.25 per cent nitrogen))

	Methods of obtaining manure	
	Traditional	Through a biogas plant
Organic matter loss by decomposition	500 kg	270 kg
Nitrogen loss by decomposition	1.25 kg	
Final manure quantity	500 kg	730 kg
Quality/11 per cent on dry basis	1 per cent	1.37 per cent
Additional advantage		2,000 c.t. of gas for cooking

Source: Government of India, "Utilization and recyling of agricultural and animal wastes/byproducts", a country report (New Delhi. 1977).

There are about six biogas plant designs available in India. Of those six, the Khadi and Village Industries Commission (KVIC) and the Planning Research and Action Division have produced the most widely used designs. The biogas (gobar gas) plant consists of two components −digester and gas holder. Digesters are constructed below ground level at places where it is easy to excavate to a depth of 15−20 feet. Vertical−type gas plants are designed where the water table is high. The materials for construction are burnt bricks and cement mortar. The gas holders may be fabricated from mild steel, ferro−cement, PVC etc. The systems in present use consist of centrally guided pipes, one fixed to the gas holder and the other to the digester. This simple arrangement delivers gas at uniform pressure. The gas holder is centrally supported and can be rotated to break the scum and also to provide agitation in the digester.

The temperature best suited for maximum gas production is 30−35° C. Below 15°C, fermentation comes to a standstill. The ambient temperature has no effect, in the case of the present designs, if the plant is covered during the night.

KVIC has also developed gas lamps operating on biogas at a pressure of 8−10 cm of water. They operate at an efficiency of about 60 per cent with the pre−mixed air facility in the burner.

The Thailand Institute of Scientific and Technological Research (TISTR) has developed a digester packed with bamboo rings on which bacteria grow in the thick black slime. Digestion is faster because of the increase in the number of bacteria, and hence a small digester can produce the same amount of gas as a conventional large unit.

The pit−type digester developed by KVIC has been used extensively in Nepal. Many farmers, however, complain that the liquid effluent valuable as a fertilizer, is difficult to transport, especially when their fields are higher than the digester.

The In−service Training Institute of the Department of Agriculture at Peradeniya University, Sri Lanka, has designed two digesters incorporating the integrated approach. The gas is used directly for cooking, lighting etc., and the residual slurry is used as a fertilizer and is also fed into a fish pond. A project in the Tangalla district involves turning bioga's, wind and solar energy to electricity, but the cost of unit power is very high in that case.

A Chinese type of biogas digester makes use of a concrete dome instead of a metal gas holder and is, therefore, much cheaper than the Indian model. There are 7 million small digesters in China for providing fuel for cooking and lighting. There are also large digesters, up to 100 cu m, to run diesel engines for electricity generation. Green fodder, such as grass, sugarcane leaves and banana leaves, are used in addition to traditional pig manure and night soil. The Chinese have emphasized an integrated biogas technology in which the biogas slurry is used as fertilizer for crops. In some places, the biogas slurry is added to fish ponds. Over 70 per cent of the biogas plants in China are in the Szechuan Basin, because the rest of the country is unsuitable for fermentation; the digesters have proved to be inefficient and prone to water and gas leaks.

The economic advantages of nine biogas installations in India are shown in table 16. There, the cost of biogas varies from Rs. 2.65 ($0.33) to Rs. 6.72 ($0.84) per 1,000 cu ft of gas produced. The table also shows that the amount of fertilizer available from biogas plants was about 60 per cent greater than that formerly available to the farmer when dung was burned for fuel. The digester and the gas holder of the biogas plant are the most expensive parts of the system, especially in rural areas where cement and steel have to be imported, and, to improve the economic viability of biogas, the cost of the digester and the gas holder should be reduced. Among the technological problems to be solved is the low yield of biogas during the winter months.

Table 16. Economic advantages of the biogas plants in Uttar Pradesh, India a/

Plant No.	Total investment in plant b/	Number of persons	Annual cost of fuel if biogas were not used	Present annual consumption		Annual capital charges (depreciation)	Annual labour charges for slurry	Annual maintenance and other charges	Interest charges (8 per cent on capital) c/	Annual cost of production	An[illegible] sav[illegible]
				Fuel	Gas cu. ft.						
1	2 400	30	1 080	–	1 34 250	80	60	24	192	356	7
2	1 500	5	310	–	52 195	50	60	15	120	245	
3	5 000	40	1 600	–	1 82 500	167	120	50	400	737	8
4	1 850	16	600	–	73 000	62	72	19	148	301	2
5	1 800	25	1 000	–	91 250	60	60	19	144	283	7
6	1 900	7	360	–	45 625	63	60	19	152	294	
7	1 500	20	620	–	54 750	50	60	15	120	245	3
8	2 000	16	564	–	91 250	67	60	20	160	307	2
9	7 000	125	3 160	600	2 02 940	233	500	70	560	1 363	1

Source: Methane Generation from Human, Animal and Agricultural Wastes (Washington, D.C., National Academy of Sciences, 1977).

a/ Costs are given in rupees (approximately Rs. 8.0 = $US 1.00).

b/ The total cost of each plant includes the cost of the digester, stoves, pipe fittings and the cost of labour involved in the installation.

c/ Current interest rates in India are higher. The state of Uttar Pradesh now charges 17 per cent interest on biogas plan.

Wind energy

Location−specific wind energy systems have great potential for meeting some of the energy demands of rural settlements. The source of wind is in the atmospheric temperature differences caused by solar radiation, which in turn give rise to pressure differentials. The wind is a mechanism for dissipating, as kinetic energy, the potential energy accumulated in those pressure differentials. A number of performance characteristics of wind energy conversion systems are applicable to the conditions of rural settlements, some of which are the following:

(a) Renewability: wind energy is a renewable resource which is not subject to the supply and demand fluctuations of energy economics;

(b) Technological complexity: windmills are available in a wide range of technical designs and, hence, are easy to match to the available technical skills and experiences of rural settlements;

(c) Scale: wind energy systems are well matched to many of the power and energy levels needed in rural settlements;

(d) Distribution: wind is a distributed resource available at the point of application, so that remote villages may be provided with power without a distribution network;

(e) Applications: wind energy technologies are well suited for water−pumping, mechanical power and electricity generation, all of which are relevant to the domestic−sector energy needs of rural settlements;

(f) Cost: wind machines usually have relatively high capital and energy production costs, but small−scale, low−capital designs may provide a cost−effective power supply over the system lifetime.

Windmill designs are classified into two categories: vertical axis − i.e., rotor mounted on a vertical axis − and horizontal axis −i.e., rotor mounted on a horizontal axis.

The conventional horizontal−axis machine with two or three blades is more popular than the non−conventional vertical axis machine. Both have undergone intensive development during the past two to three decades. The most famous of this class of machines was the Smith−Futnam windmill installed at Grandpa's Knob in Vermont, United States of America. It had a rotor diameter of about 55 m. and two blades of stainless steel. It was supported on a tower 30 m. tall. At a wind velocity of about 30 km/hr, it generated 1 MW of power.

The successors to that machine are the NASA/DOE* MOD 0 and MOD 1 machines of the United States of America and the GROWIAN of the Federal Republic of Germany. Of those, MOD 0 was designed for 200 kW, and MOD 1 for 2 MW. The GROWIAN I was designed for 2 MW, and its larger version GROWIAN II for 5 MW. These are large−scale machines which are suitable for high−wind conditions; unfortunately, such conditions are not available in most developing countries.

* National Aeronautics and Space Administration/Department of Energy.

In a lower range, on the order of 100 kW, a large variety of designs is available. Most of them have comparatively poor performance histories and are also quite expensive to operate and maintain; they are mainly useful in places with good wind conditions.

For small communities, small machines for generating 20−50 kW would be convenient, especially considering the power consumption patterns of developing countries. In that range, both horizontal−axis and vertical−axis machines have been found to be adequate. There is considerable information available on horizontal−axis machines, but information about vertical−axis machines is scanty.

The vertical−axis machine consists basically of a short framework in the form of a tower or stand to which a vertical shaft is attached. Blades having the cross−section of a symmetric profile designed by the National Advisory Committee for Aeronautics (NACA) (the most popular being 0012) are bent longitudinally into the shape of a catenary and fixed by means of bearings to the top and the bottom of the shaft. Usually two or three blades are used. The entire assembly is in the shape of an egg−beater. When the wind blows past the blades, thrust is generated, developing a torque about the shaft axis, thus rotating the machinery. The power is tapped at the bottom of the shaft.

From the point of view of technical considerations, it appears that water−pumping is the most attractive application for wind energy. Specific power requirements for water−pumping depend upon the depth of water, source or pumping distance, and the operating characteristics of the pump. To supply domestic consumption, power requirements of no more than 100 watts would be sufficient. A wide variety of locally available materials could be used in the fabrication of windmills, but the availability of precision components such as gears, chains and crankshafts might be a problem, particularly in the remote areas of developing countries. In general, the initial capital cost of windmills is high relative to the income of the rural population or urban poor.

In wind−power utilization, the larger the machine, the more economical the performance; however, increasing size is limited by structural problems as well as by the non−uniformity of wind velocities over large areas. The size of a windmill is also limited by the economic−analysis for a specific site, and the output varies according to the type of work being done. Multivane machines produce high torque but low revolutions per minute, and hence are best suited for lifting tasks, such as water−pumping. On the other hand, two−vane and three−vane machines produce high revolutions per minute and low torque, and consequently are best suited for generating electricity. It is apparent, therefore, that, for every specific location and task, an optimum size and design exist.

Although wind machines have economically performed certain tasks in various settings for centuries, the range of applications has been growing recently owing to increased experimentation and the adoption of new technologies, such as inverters, hydraulic energy absorbers and light−weight alloys. Within the past five years, the Philippines, Thailand and Peru have all seen successful wind−machine enterprises take root in specific localities, but those cases are exceptions. A commonly cited constraint to the successful introduction of wind programmes in developing countries is simply the lack of trained manpower to organize, deploy and direct such exercises as assessing wind energy magnitudes; advising on siting, designing, selecting and installing hardware; gathering and disseminating field−test data; and administering outreach programmes. To correct the situation, regional wind−energy training centres have been cited as a necessary measure. The staff of such organizations, supplemented by expert consultants, should be able to produce co−ordinated programmes of wind−power exploitation based not only on assessments of new developments but also on their own original research and development. 25/

Although a great many innovative devices are being built and tested in the laboratories of industrialized countries, such as wind augmenters and diffusers, and vortex generators, it may be decades before they meet the immediate needs of low−income residents in developing countries. Designs of multibladed windmills well suited to conditions in developing countries have recently been developed, and a number of such new designs are undergoing trials in India, Kenya, Peru, Sri Lanka and elsewhere. However, they do not yet seem to be suitable for the majority of potential users. To meet the demands for water pumping on the part of subsistence farmers, new types of sail windmill have been developed and tested in countries such as Colombia, Ethiopia and India. Despite the fact that their fabrication cost is roughly one quarter that of imported multiblade windmills, the dissemination of the technology remains disappointing. Such facts indicate the need for a well−organized international outreach programme to bring the benefits of wind energy technology to where they are most needed.

Small−scale hydropower

Small−scale hydropower installations are one low−cost means of supplying power to settlements at significant distances from electrical grids. A hydropower installation consists very simply of a closed conduit (ordinarily a large−diameter pipe for small plants) that feeds water available at a certain height (head) above a hydraulic turbine which converts the power of the falling water to shaft power. In hydroelectric plants, the turbine is coupled to a generator which converts the shaft power to electricity (either DC or AC).

Hydroelectric energy in small quantities has a great potential for meeting the basic energy demands of rural communities and, further, could provide the energy necessary for rural industries. Increasing attention is being paid to small installations of 100 kW or less, and it is estimated that a 100–kW facility could be installed in a waterfall with a 6–m head (the vertical distance the water falls from inlet to outlet) and a flow of 1.5 m^3 per second. For instance, it is reported in China that about 50,000 hydroelectric plants have been constructed within the past decade with an average capacity of 35 kW. The contribution of small–scale hydropower to their national output was calculated at approximately 7.5 billion kW in 1974, or over 50 per cent of rural electric power consumption. The development of facilities such as the bulb–type self–contained turbine generator with remote control is expected to expand the use of small–scale hydroelectric installations.

Many rural settlements, particularly those that are mainly involved in agriculture, are located near streams and irrigation canals with flow and fall sufficient to power mini–hydroelectric units. The cost of such units varies widely, depending on topography (slopes, storage, evaporation), geology (dam location, run–off) and stream flow (rainfall, drainage basin area), (see table 17). In the United States of America, commercially available small–scale turbine units are priced from $3,000 for 0.5 kW to about $10,000 for 10 kW. In the United Kingdom, commercially available hydroelectric units operating under a 3–m head cost around $34,000, and for a 4.5–m head about $28,000. In addition, small–scale hydro–units have been developed in Canada, the Federal Republic of Germany, Hungary and the USSR. A 3–kW mini–hydroelectric scheme which was installed in a village in Fiji on an experimental basis in 1975 still has excess capacity after meeting the lighting demands of 17 houses. The installation cost, excluding labour, was only $7,500. 26/

The effective utilization of hydropower requires a site with sufficient head and flow. In large installations and in some small ones, the flow must be year–round. For rivers where the flow is seasonal, dams must be built to allow flow regulation to meet demand. However, in some small–scale applications where flows are seasonal, it may be possible to utilize the power available from a river on a seasonal basis and avoid the cost of building a dam. 27/

The utilization of hydropower in developing countries is often retarded owing to the lack of hydrological, topograhical, geological and economic data. Since most of the unused hydropower potential is found in developing countries, the issue of data availability becomes crucial. The absence of legal standards and conflicts over water utilization rights also inhibit the utilization of hydro sites.

Where good hydro sites are available near load centres, hydro is the least expensive source of energy available, but, when transmission lines for the electrical power are more than a few kilometres long, cost of the power produced rises rapidly. 28, 29, 30/ Utilization of good hydro sites should therefore be a factor in the location of new settlements. For instance, if hydro–powered market centres were developed for receiving and processing agricultural crops for shipment to urban centres, some economic activities and employment could be moved from urban to rural areas.

Table 17. Breakdown of fixed cost for micro–hydro plants of 5–40 kW capacity (Pakistan rupees)

Plant capacity (kW)	Total installation cost	Fixed cost (per kW), installed	Distribution cost	Total delivered cost	Fixed cost/kw delivered
5	29 800	5 960	8 000	37 800	7 560
12	43 460	3 622	16 000	59 460	4 955
20	58 170	2 908	20 000	78 170	3 908
40	93 895	2 347	30 000	123 895	3 097

Note: The above–mentioned costs are highly specific to the site condition and do not related to the installed capacity of the plant only. In particular, the cost of penstock depends heavily on the size and length of the pipe. In certain places, cost of cement is substantial if lining portions of the power channel becomes essential. The cost of distribution mentioned above is again specific to the location of the power house, the distance between the power house and the areas to be served. The cost of generator and turbine is fairly representative of the capacity installed. The installation cost is an average.

The development of both large and small hydro sites requires the completion of feasibility studies based on extensive field work. Flows and heads must be measured, and hydrological data analysed in order to estimate variations during the year. For small–scale plants, the feasibility study may absorb a large portion of installation cost unless an ideal site is available.

The country with the most extensive experience with small–scale hydropower for electrification is China. One hundred thousand installations with an average capacity of 70 kW have been installed there during the past two decades. The selling price of electricity from those hydro plants is about half that of electricity from conventional steam plants and the construction and operation of the hydro plant is the responsibility of the community using the power. 31/

Hydraulic turbine technology is well developed, both large scale and small scale. Turbines are available from many manufacturers, primarily in developed countries. However, a few countries, (e.g. China, have started manufacturing small turbines of the cross−flow type. 32/ As can be seen from the Chinese experience quoted above, hydro−turbine technology has developed to such an extent that, over two decades, the average capacity of installed turbines has fallen from 105 kW to 35 kW.

Experience with rural electrification projects extended from national electrical grids has shown that electricity has only marginal value for low−income people since they usually cannot afford it. However, small−scale hydro installations designed specifically for increasing rural productivity have a potential for meeting the basic needs of low−income rural people.

Wood

In the industrialized countries only 1 per cent of the total primary energy is generated at present from wood−based fuels. However, the predicted crisis in wood−energy resources for the rural low−income population in developing countries already affects a large number of people. According to the Food and Agricultural Organization of the United Nations (FAO), of the 1,165 million m^3 of wood consumed in the world in 1977 as fuel, 1,030 million m^3 was burnt in the developing countries. FAO estimates of the number of people now affected by fuelwood shortages in developing countries and projections of the increased number affected by the year 2000 (see table 18) underscore the rural nature of the crisis. As of 1980, the total population affected by deficits and scarcities in wood fuels to meet basic needs is expected to grow by nearly threefold in the next 20−year period, to the alarming number of 3 billion.

Table 18. The fuelwood shortage in developing countries (Millions of people affected)

	1980				2000			
Region	**Acute scarcity**		**Deficit**		**Acute**	**scarcity**	**Deficit**	
	Total	**Rural**	**Total**	**Rural**	**Total**	**Rural**	**Total**	**Rural**
Africa	55	49	146	131	88	74	447	390
North East and North Africa	−	−	104	69	−	−	263	158
Asia and the Pacific	31	31	645	551	238	53	1 532	1 411
Latin America	15	9	104	82	30	13	523	235
Total	101	89	999	833	356	140	2 770	2 225

Source: F.H. Pasca, "Concerning wood energy", Unasylva, FAO, vol. 33, No. 131 (1981),

The most serious aspect of the wood shortage is that the attempts of people to secure adequate supplies for their domestic needs −including wood as a building material − reduce the ability of the ecosphere to replenish itself. When yearly wood harvests exceed the annual yields of forests, the standing stocks (or forest capital) are depleted. In Kenya, a recent energy survey showed present wood−energy demand to be 18.7 million tonnes. 33/ At present, only 13.0 million tonnes are supplied from sustainable yields, the balance of 5.7 million tonnes being harvested from forest capital. The expected increase in this case (which assumes the continuation of present fuelwood policies) of fuelwood production shortfall is sixfold, shortly after the turn of the century.

Besides causing a shortage in wood−fuel supplies, the depletion of wood stocks has other consequences. The uncontrolled cutting of trees causes deforestation, which results in deterioration of soil quality and reduction of groundwater for plant growth, leading to decreased food production and lowered nutritional quality of the food produced. As wood resources become scarce, people burn dung and crop residues which are essential for maintaining soil fertility. Only two methods are available for remedying the crisis: conservation in wood−fuel utilization and establishment of new fuelwood reserves.

Wood conservation

Conservation takes the form of the efficient use of wood, such as the use of efficient cookstoves to replace open fires, and the efficient production and utilization of charcoal. Wood consumption can be reduced by a factor of eight through the use of well−designed stoves. However, care must be taken to choose the right types of new stoves so that they can be used in existing buildings without creating smoke problems. Problems relating to low–cost production, the diffusion of know–how and large–scale commercialization will also have to be solved, since the main users of the stoves will be the poorest people in the community.

So far, efforts to increase the use of wood–burning stoves has had limited success. Certain improved wood–burning stoves that were slightly more efficient than traditional ones proved to be less durable under rural conditions. The public reluctance to use improved wood–burning stoves can be attributed to a number of factors, such as incompatibility of the new stoves with cooking habits, poor design, high initial cost and very marginal improvement in efficiency.

Traditional cooking methods have several undesirable characteristics:

(a) Lack of control – the intensity or rate of burn of open fires is difficult to control and may restrict the preparation of some kinds of food or limit the choice of cooking methods;

(b) Unhealthy conditions – family members, especially the cook, are– constantly exposed to smoke and soot in the kitchen area and, in many cases, throughout the house;

(c) Hazards. Open fires subject family members and especially unattended children to possible burns and scalds from sparks and unstable cooking pots, and expose combustible structures to possible fire damage;

(d) Insanitary food preparation. Built–up soot in the kitchen area and roaming animals, such as dogs, may bring filth in contact with food cooked low to the ground over an open fire;

(e) Lack of cooking space. Often only one food item can be prepared at a time, and a supply of water cannot be kept hot while food items are prepared;

(f) Fatigue. Open fires often require constant tending or fanning by the cook who is exposed to the heat emitted by the fire;

(g) Indirect costs. Family members expend considerable time, labour or money to obtain the large amounts of firewood needed for open–fire cooking because of the poor efficiency of wood use.

Some important factors to be considered in the introduction of improved cooking stoves are:

(a) The design of the stoves must produce a substantial improvement in cooking methods and consequently in living conditions;

(b) After research and development on engineering aspects have been completed but before the use of new stoves in rural areas is promoted, the stoves must be extensively field–tested;

(c) Since no "universal" improved stove exists, extension programmes to promote the use of stoves will have to start by identifying, for a given country or region, what modifications in existing conditions are necessary, due account being taken of cultural issues and food habits;

(d) Financial and technical assistance programmes should consider the introduction of efficient stoves as a standard feature in relevant programmes, such as those related to fuelwood plantations.

The main objectives of stove design are to achieve cooking efficiency and provide for water–heating. Significant shortcomings and inconsistencies are, however, found in the efforts to test cooking–stove performance. For example:

(a) Laboratory tests tend to use cooking stoves which are specially constructed for tests under closely controlled conditions;

(b) Laboratory tests typically utilize specially prepared fuelwood or other fuel;

(c) Laboratory tests are based on water–heating trials that do not accurately reflect rural cooking practices;

(d) Laboratory test data are not directly comparable in most cases because of the use of inconsistent testing procedures and data collection methods;

(e) Laboratory test data currently available appear to be unreliable, not easily validated and, in many cases, inconsistently or incorrectly reported;

It is clear that there is a need for research and development on the engineering aspects of stoves and that extensive testing – field testing, in particular – is required before new cooking stove designs can be promoted in rural settlements.

Efficient production of wood

In rural settlements, where nearby forest areas are no longer adequate to meet primary energy needs related to cooking, the rational management of forest resources and fuelwood plantations may provide the answer. The renewable nature of forests makes possible a sustained output of wood for fuel and building materials. Fuelwood plantations also provide substantial ecological benefits, particularly if animal waste (which today is being burnt as fuel) is returned to the soil as manure in order to increase the productivity of the soil and prevent soil degradation. Another advantage is the reduction in the time and labour devoted to the collection of firewood – time and labour which can be used in productive ways to increase rural incomes.

A constraint to the development of fuelwood plantations is the unavailability of land and the time it takes to grow trees. There are also institutional constraints relating to such factors as land–ownership and tenure patterns and land–use practices which do not allow for or encourage the setting aside of land for tree plantations. Other factors affecting the development of fuelwood plantations are climatic and soil conditions and local community responses to governmental policies on forestry services.

Because of the demand for land for agricultural and settlement development, fuelwood plantations may be a more viable proposition at the community level than at the individual level. The rate of wood production in carefully managed plantations of fast – growing fuelwood species can be more than five times that of an indigenous forest covering an equivalent area. Innovative approaches are needed in the choice of species in order to minimize the problem of time–lag between planting and production. Significant results have been achieved in meeting local firewood needs in parts of Indonesia through planting calliandra calothyrus, a vigorously coppicing and branching tree shrub which, if cut back at age of 8–12 months to encourage coppicing, can produce usable firewood from the first year.

However, an objective evaluation of the costs and benefits of forest fuelwood plantations is difficult. It involves factors such as the yield of fuelwood per hectare per annum, the growth period of trees, the cost of land in terms of its opportunity cost, and the initial and recurring cost of establishing and maintaining the plantation. For example, experiments at a fuelwood "energy plantation" in the Philippines indicated that a 900–ha tree farm of Ipilpil would produce enough wood to fuel a 75–MW power plant. It also indicated that a wood–fired electric generating plant could not only compete economically with an oil–fired plant but could save an estimated foreign exchange commitment of over $146 million in its first 10 years of operation. The utility of such fuelwood plantation schemes could be improved by applying technologies of distilling wood instead of burning it in domestic cooking stoves. For instance, a pilot scheme in Ghana indicated that a 40,000–ha plantation of fast–growing trees could produce 50,000 tons of methanol, 20,000 tons of pyrolytic oil, 150,000 tons of ammonia fertilizer, 17,000 tons of char and 80,000 kWh of electricity, plus food crops. In view of these figures, fuelwood plantations and the associated processing technology could well be the way to meet the energy demands of rural and urban settlements. However, when wood species are chosen for growth, characteristics such as the heat value of the wood, odours, resins, and the speed of burning should be taken into consideration.

The importance of fuelwood for the domestic sector should be given special emphasis in the management of forest resources. Traditional forest–management techniques, forest–resource inventories, soil surveys etc. do not consider the implications of the fact that forests represent a source of energy for the rural poor. Policies and planning for integrated forest–resource management should consider, among other things, the establishment of village or community woodlots, the planting of trees that produce timber and fibre suitable for use as building materials, and the encouragement of small–scale rural industries that use wood.

Charcoal production

The conversion of fuelwood into charcoal produces a cooking fuel with approximately twice the heating value per unit weight of wood. The average heating value of charcoal is about 7,400 kcal/kg, whereas that for air–dry wood is about 3,700 kcal/kg. Charcoal has always been preferred over firewood in many regions of the world, by both the urban poor and rural populations. The use of charcoal is now predominantly confined to urban low–income groups owing to the non–availability of cheap firewood around urban settlements. The processing of wood to charcoal normally results in substantial weight and energy loss, and, in rural areas, 50–84 per cent of the energy in wood may be lost during conversion. Depending upon the processing methods employed, about 15–35 per cent of the energy originally contained in the wood is retained in the charcoal. Charcoal is easier to transport than wood, and it is from three to four times more efficient in conversion to heat energy. Traditional charcoal kilns operate at 5–10 per cent efficiency in converting wood to charcoal by weight. The cost of charcoal is highly variable and is constantly escalating, owing to the scarcity of indigenous hardwood forest trees. Advanced technologies of wood distillation provide not only charcoal but also pyrolitic oil, methanol etc.

Improvement in kiln design can result in significant increases in yields. Metal and brick kilns have much higher yields than traditional earthen kilns. When wood is properly dried before pyrolysis in some areas, by solar drying, some of the heat required to evaporate water from the wood is conserved. 34, 35/

The utilization of a large percentage of the heat content available in wood during pyrolysis is possible with charcoal retorts. The retort and associated equipment is able to distill a variety of wood products, including methyl alcohol, acetic acid, esters, acetone, wood oil, creosote oil and pitch. Wood gas is also a pyrolytic product. The potential for the utilization of gas distillation products is very high for developing countries. Unfortunately, the technology for retort design and operation is not yet available for the conditions where it is needed, although research in the area continues. 36, 37/

Rural charcoal–making is still part of the informal sector and is confined to people who have limited access to investment capital and whose technological experience and access to information are severely limited. In searching for suitable sources of income, entrepreneurs in the informal sector generally concentrate on those segments of the market which the formal sector cannot, or chooses not to, exploit itself. This is perhaps the reason why charcoal–making in earthen kilns (made by covering a pile of wood with a layer of dirt) is very popular in rural communities. Rural energy policies in respect of charcoal should be based on the following principles:

(a) Steps should be taken to promote the improvement of designs of charcoal kilns for rural applications;

(b) In promoting the production and use of charcoal, due attention should be given to factors such as the harvesting and transport of fuelwood, the transport of charcoal to market centres for distribution, deforestation and other environmental problems.

Wood gas

During pyrolysis a gas is produced from wood which is combustible in internal combustion engines. The primary combustible components of the gas are carbon monoxide, hydrogen and methane. Composition varies, but the calorific value is approximately 4,000 kJ/m^3. 38/ This is of relatively low calorific value compared, for example, to methane at 38,130 kJ/m^3. However, the potential to produce shaft power and generate electricity from wood–fuel resources is one very important prospect for that renewable resource. It is notable that pyrolysis is one of the few conversion processes for a renewable energy resource which results in a fuel for transportation.

For small–scale power needs (less than 10 kW), standard internal combustion engines can be converted to run on wood gas. Diesel engines can be run on a combination of diesel and wood gas, which saves about 90 per cent of the diesel required for the same power output, which in that mode is roughly 80 per cent of the power on diesel alone. 38/ Diesel engines may also be converted to spark ignition to run on wood gas only. Unfortunately, a number of other modifications are also required which make this a rather expensive alternative. Spark ignition petrol engines are rather simple to convert to wood gas and are probably the best choice for small–scale applications. Petrol engines produce approximately 60 per cent of their normal rated power on petrol when operating on wood gas.

Although wood–gas technology has not been widely utilized in recent years, it has quite a long history. Gas from organic fuels was used to fire blast furnaces over 180 years ago. During both World Wars, and especially during the Second World War, wood gas, or "producer gas" as it was called, was widely used in Europe as a fossil–fuel substitute. When petroleum fuels became very inexpensive, wood–gas technology was abandoned. However, many international research centres and commercial firms have continued their research and development efforts in the field. One manufacturer in Sweden is prepared to deliver and install gas producers for automobile engines, stationary engines (e.g., agricultural machinery), complete generating sets, complete pumping sets, complete mobile sawmills and special charcoal kilns for the greatest efficiency in fuel preparation. 39/ Gas producers using either wood or charcoal as fuel are available.

Integrated energy systems for rural applications

The conventional method of supplying energy by means of rural electrification has not alleviated the energy problems of rural settlements. Given the subsistence levels of energy consumption in rural areas and heavy dependence of rural populations on non−commercial fuels, strategies to increase the level of energy availability and ensure an uninterrupted supply of energy should emphasize the use of non−commercial fuels and adopt new technologies to maximize the benefits from renewable energy sources, which are at present underutilized. The evaluation of technologies to exploit renewable energy sources in rural settlements, carried out by various agencies in the recent past, has led to widely varying conclusions. One of the reasons for the diversity of findings is that energy technologies are now in a state of development, and some of the devices to convert renewable energy into useful end−use energy (e.g., heat) under typical rural conditions are still undergoing extensive field−testing.

Furthermore, there are no clear−cut surveys on the energy needs of typical rural communities or on how much existing rural energy consumption must be increased in order to achieve the goals of overall integrated rural development. In planning for general rural development, therefore, an assessment of energy needs is required.

Energy supply in rural areas is needed for the following purposes:

(a) Household cooking;
(b) Household heating and cooking;
(c) Household, commercial and public lighting;
(d) Water supply;
(e) Agricultural land preparation, irrigation, sowing and harvesting;
(f) On−farm transport;
(g) Transport of fertilizers, seed etc. to farms;
(h) Transport of produce to market or for processing;
(i) Household and non−household industries.

Once a profile of energy requirements has been made, it is necessary to examine conventional and non−conventional energy sources and the technologies required for converting them into end−use energy. The extent to which each energy source should be exploited varies from region to region and between and within countries.

The location−specific and intermittent nature of some renewable energy sources, which dictates the need for an energy−storage facility, is a problem in their utilization. Most of the research and development efforts on the use of renewable energy sources carried out so far have been based on the applicability of a single source (such as solar, wind or biogas), either as a substitute for a conventional source or as a potential energy supplement to meet growing demands. Although it is necessary to emphasize the development of commercially viable technology for exploiting renewable energy sources independently, an integrated approach, using all locally available resources (including commercial ones, where available), would not only maximize the benefits obtainable from the renewable sources but also ensure an uninterrupted supply of energy. There seems to be considerable promise for such integrated energy systems in rural areas. A great deal of local effort must be marshalled to assess the needs of the different segments of the population and to modify technological procedures to suit local settlement conditions. 40/

For instance, an assessment of the electrical and thermal needs of rural settlements shows that waste heat generated, for example, from a solar thermal power plant can be utilized in any of the following ways: to heat water; to circulate hot air in crop dryers and perform other post−harvesting functions; to maintain constant temperature conditions around biogas digesters for the optimum yield of gas; and to keep food cool.

Electrical energy will probably be used primarily for irrigation−water pumping, rural industries (cottage industries and repair shops), and street and public−building lighting. Since an irrigation system may need electricity for only about 1,000 hours a year, the economics of using electricity, even from a decentralized system, for such a low–load factor will have to be examined vis–a–vis other options. Should electrical energy be found cost–effective for running post–harvest devices, such as rice hullers, rice mills, sugarcane crushers and oil extractors, the load will remain relatively uniform over the year.

A biogas plant will provide all the fuel needed for cooking, and the surplus, if any, can be used to run prime movers and to back up solar systems on cloudy days and at night. Some of the waste heat from solar systems can be used for maintaining a constant temperature in the digester, thereby maximizing the production of methane. If photovoltaic and/or other electricity generators (windmills or water–mills) are used, they can all utilize the same storage, distribution and control equipment, thereby reducing costs. Pumping requirements can be met in a variety of ways from such a total energy package (electricity–driven, biogas–driven, mechanically driven from windmills, or directly solar–driven), depending on local conditions. Decisions will have to be taken on the basis of local optimization studies. The feasibility of integrating various energy sources should be considered from the perspectives of:

(a) Increasing the conversion efficiencies to useful energy of various primary energy sources;
(b) Providing reliable energy supply;
(c) Having the least adverse environmental impact;
(d) Enriching the quality of life relevant to the socio–cultural fabric of the society.

It is apparent that there are various options but no proven solutions available for supplying rural energy needs. It is therefore necessary to utilize a mix of the available options and technologies in a locally beneficial manner.

Chapter IV. CONSTRAINTS AND BARRIERS

A number of constraints and barriers affect the development of domestic energy projects. The include the following:

(a) The absence of sectoral co–ordination in national energy planning;

(b) The inability of local planning authorities to deal with the problems of the domestic energy sector;

(c) The inefficiency of administrative mechanisms for maintaining domestic energy–supply systems;

(d) The tendency to prevent industry and the public at large from playing active roles in settlement planning and energy planning.

New forms of co–ordination are needed in the various governmental agencies that deal with domestic energy matters, in order to maximize benefits to communities through the implementation of projects based on available resources. A programme for the supply of energy to the low–income population implies the adoption of special measures such as the establishment of mechanisms for the promotion of renewable energy sources and the rational use of commercial fuels.

Great effort and long–term commitment at local, national and global levels are required for the development, transfer, adaptation and dissemination of technologies for the exploitation of renewable energy sources. The traditional economic criteria used to determine the feasibility of large–scale, capital–intensive energy projects should be reviewed in order to take account of other objectives, such as improving the quality of life for and increasing the productivity of low–income groups. The main obstacles standing in the way of the use of renewable energy technologies are: 41/

(a) High initial capital investment relative to traditional commercial fuels;

(b) Lack of adequate and systematic knowledge about renewable energy technologies and about anticipated developments in energy conversion and storage;

(c) Insufficient information on the socio–economic benefits and costs associated with technical options;

(d) Inadequate awareness of market potential;

(e) Limited commercial availability of renewable−energy conversion equipment.

Such shortcomings can be reduced to some extent through the use of integrated energy systems consisting of several subsystems.

The current strategy of some national Governments and development organizations is to promote the use of small−scale energy systems at the individual household level in rural areas. Although that strategy benefits a certain number of people − generally the high−income rural population − its impact may be small in the overall context of national energy planning.

In order to meet the energy requirements of the economically weak sections of the population, energy policy−makers should consider the promotion of integrated energy systems at the community level. Community−level systems not only provide a reliable supply of energy but also help to develop institutions for dissemination and maintenance and create the necessary environment for socio−cultural acceptance.

Financial institutions involved in the development of human settlements must play a leading role in providing human and financial resources for projects dealing with the provision of energy to rural and urban settlements. Without the support and co−operation of development banks, it is difficult and unwise to launch important energy−promotion projects aimed at aiding the economically weak segments of the population.

In many developing countries, although potentially viable projects in the field of renewable energy exist, there is a dearth of entrepreneurial and managerial skills. Development banks are increasingly aware of the situation, and offer training programmes for senior managers and administrators, and have even provided managerial advice for some projects. Within the framework of their overall objectives related to the fostering of economic and social development, the World Bank and the regional development banks have recognized the importance of encouraging the utilization of renewable energy sources Co meet rural energy requirements. The support of such banks takes the form of:

(a) Technical assistance operations for pre−investment studies; the transfer, development and adaption of technology; the creation and strengthening of institutions for sectoral planning, policy formulation and investment programming;

(b) The financing of high−priority and viable capital−investment projects or programmes formulated in accordance with national or regional socio−economic development plans and objectives.

Chapter V. POLICY CONSIDERATIONS

Settlement policies and planning, and energy priorities

Priorities for development in rural settlements and poor urban settlements must be based on a rational distribution of human and financial resources, a deliberate and conscious mobilization and allocation of resources for providing adequate energy supply and the development of innovative energy policies as an integral part of settlement policies and strategies. In most current planning models, emphasis is placed on physical and spatial aspects of urban development rather than on economic and social factors which are fundamental influences on human settlements development. Integrated energy use, whether in rural or urban settlements, is so complex that both economic and human settlements planners have at best a limited quantitative understanding of the energy factors involved in long−range planning of human settlements. One of the difficult problems faced by the human settlements planner is that there are no systematic investigations into different aspects of energy fluxes in structural patterns of settlements, which would yield a coherent picture of the impacts of energy management on human settlements.

Planning for the improvement of rural conditions should cover such areas as enhanced productivity, increased levels of employment and improved access to food, shelter and educational and health facilities. To reach these goals would require a great increase in the energy base in rural areas, and planning should therefore include the adoption of technologies which can ensure an uninterrupted supply of energy to rural areas. Since a large percentage of the rural population is involved in agriculture, in most cases at subsistance levels, measures aimed at expanding agricultural output and improving the quality of life in rural areas might include provision of pumped water for domestic and agricultural sectors, provision of transportation facilities for agricultural−produce distribution, marketing and storage, provision of energy for cooking, water heating and lighting, rational management of agricultural residues as feed−stock for energy and fertilizer production, and provision of energy for rural industries.

Settlements planning for urban areas in most developing countries must deal with the increasingly acute problems of the urban poor living in slums and squatter settlements. The problems of the urban poor include unemployment, lack of adequate infrastructure, poor housing conditions and shortages of social services and amenities. Energy−consumption patterns in the domestic sector for urban areas indicate that use of non−commercial fuels is mostly confined to low−income people. Faced with the scarcity of non−commercial fuels, the urban poor find it increasingly difficult to meet the rising costs of commercial fuels, such as kerosene and bottled gas.

The integration of human settlements planning and energy planning in a wide socio−economic framework encounters one particular obstacle of great importance: energy planning and crucial energy−supply decisions are usually made at the national level, whereas most settlements planning is done at the local or community level since most Governments delegate responsibility for management of communities to local administrations. Yet, decisions at the community or local level on infrastructure and services profoundly influence overall national energy use. For instance, any decisions at the local level on improving the conditions of poor rural and urban settlements imply an increase in consumption of energy, yet the planner is either unable or unauthorized to make any decision on projects that provide for such an increase. Decentralized settlements planning and centralized energy planning create a situation marked by lack of co−ordination, duplication of efforts and ultimate failure of planning in achieving objectives.

Any co−ordinated approach to improving the quality of life for the rural poor and urban low−income groups involves a commitment to increasing energy supply. In the context of integrated human settlements planning and national energy planning, the following energy policy options for settlements planning should be considered:

(a) The development of indigenous planning models and methodologies should be given priority, so as to promote the efficient use of energy resources and the application of emerging technologies in utilizing renewable energy sources;

(b) Settlement planning should be co−ordinated with energy planning in order to ensure adequate energy supply for domestic use of low−income groups;

(c) Settlement planners should take energy aspects into considerations in planning spatial relationships among land uses and in designing the layout of settlements, particularly for the urban poor, and should integrate infrastructure and transportation planning to utilize energy resources efficiently;

(d) Planning for rural settlements should form an essential part of integrated rural development, including rural industrialization, and should specifically deal with the problems of energy supply to meet the needs of the rural population.

While the need for wide−scale use of renewable energy sources is accepted by most energy and human settlements planners, efforts to include renewable energy projects at the local settlements planning level are lacking in most developing countries. Adaptation and development of renewable energy technologies are necessary, but perhaps even more important is the accumulation of experience on transferring those technologies to low−income groups in both urban and rural areas. In order to promote the application of renewable energy sources, human settlements and energy planners need information on the following:

(a) Domestic energy consumption and requirement patterns, so as to develop energy−needs criteria on which policies should be based;

(b) Local potential for fabrication, operation and maintenance of equipment, for ensuring a reliable supply of energy;

(c) Institutional, administrative and management capability for designing and implementing technological adaptations;

(d) Socio−economic and cultural attitudes in low−income communities;

(e) The precise inter−relationships between energy supply and other settlement parameters in order to identify workable policy options.

In most developing countries, Governments have begun formulating energy policies, but such attempts have been generally confined to supply−and−demand aspects of the commercial−energy sector which provides energy for industry, transportation and services. Policies for the use of energy in low−income urban and rural areas are either indadequate or non−existent, but, in the absence of a broad−based energy policy, it is difficult for the human settlements planner to deal with problems of domestic energy supply. It is imperative, therefore, that Governments give priority to formulating energy policies as a part of integrated development policies.

Policy options for human settlements

In the context of human settlements policies as an integral part of national economic development policies, the following priorities in shelter, infrastructure and services should be considered:

(a) Rural settlements built as an integral part of rural development programmes should consider renewable energy utilization;

(b) Governments should promote the use of traditional building materials based on natural products and, where necessary, promote the use of less energy−intensive methods for producing building materials;

(c) The development of performance−oriented building and infrastructure codes and standards should be geared to the economical use of energy;

(d) Appropriate medium−scale and small−scale technologies for the manufacture of building materials and components should be promoted, possibly using low−grade and medium−grade heat energy derived from thermal electric power plants;

(e) Domestic energy surveys should be carried out to provide information on sector use, in order to assess the energy needs of low−income rural and urban groups;

(f) The choice and promotion of innovative energy technologies should be based upon physical factors, such as climate, topography and natural resources, and on the overall economic development strategy that is being followed;

(g) Rural energy policies should emphasize the use of decentralized and integrated energy systems and should consider utilizing a mix of various potential and proven technological options in a locally optimized manner for the efficient conversion of primary energy into end−use energy;

(h) Rural electrification policies, particularly for remote settlements, should be examined in terms of rural energy needs, with emphasis on assessment of distribution costs, levels of consumption and the potential of other fuels available for substitution;

(i) The potential for energy conservation, particularly in the domestic sector, should be taken into account in the design of buildings, neighbourhoods and household devices as well as in building maintenance and management;

(j) In view of the dominant role played by firewood and charcoal in meeting rural energy needs, there should be an assessment of the technical and economic feasibilities of energy plantations and of the comprehensive management of forest resources in the context of integrated rural development policies;

(k) Principles of bioclimatic design should be applied in city, neighbourhood and building planning.

Priorities and policy options in public participation, institutions and management

Habitat: United Nations Conference on Human Settlements recommended that public participation should be an indispensable element in human settlements planning, development and management, and that "it should influence all levels of government in the decision−making process to further the political, social and economic growth of human settlements". Public participation is necessary for the successful adaptation of energy technologies to meet the energy demands of the poor sections of the population. A range of social constraints might also inhibit the use of new technologies, unless public participation is taken into account in planning and development to meet domestic energy requirements. In the context of human settlements development and energy planning, particularly for the poor segments of the population, the following factors should be considered:

(a) There should be extensive field−testing of energy technologies under typical conditions to assess social impact;

(b) A social cost−benefit analysis of energy options should be carried out before promoting any particular technological option to meet energy requirements in human settlements;

(c) A programme of pilot and demonstration projects designed specifically to assess social benefits should be promoted.

Energy planning for human settlements cannot be implemented without appropriate institutions. Political, administrative or technical institutions related to various development sectors must be designed to play an appropriate role in integrated development programmes, including energy production programmes. A number of problems arise in the development and implementation of human settlements and energy−related projects which call for institutional and management innovations. Human settlements institutions should, among other roles, provide the administrative, management and financial resources for domestic energy planning and the implementation of projects to meet the energy requirements of the population, particularly the low−income groups.

The following factors should be considered:

(a) Energy programmes should include the establishment of centres which promote the use of renewable energy resources in various economic sectors and perform such tasks as dissemination of up−to−date information, testing and quality control, demonstration projects, and education and training;

(b) Energy programmes should include the establishment of financial mechanisms for the development of energy technologies;

(c) Research bodies should study the use of new energy sources in relation to the development of human settlements, as well as new technology for meeting domestic energy requirements;

(d) Policies should give consideration to the establishment of integrated energy systems, using all available energy resources, as part of integrated community service units which would meet energy requirements for domestic use and for educational, medical, business, recreational and communications services.

Chapter VI. SUMMARY POLICY OPTIONS

Comprehensive planning

The priorities at the national and international levels regarding the problems of energy and human settlements should be considered on the basis of the short (5−10 years), medium (10−20 years) and long−term (over 20 years). Long−term objectives should establish the overall framework within which other decisions are taken. Thus, certain critical parameters and indicators should be established to serve as guidelines so that short− and medium−term solutions do not create greater problems in the long run. Some of the critical factors which will have to be considered are the ecological impact of energy systems, the deforestation of large areas, pressure on land use, energy requirements for food production, economic and social impacts of introducing new technologies and systems in rural settlements, changes in the pattern of energy requirements and consumption of the urban and rural poor. and long−term capital−intensive and energy−intensive industrialization policies.

The experience in many countries indicates that there is a need to plan and implement energy and settlement policies in conjunction with extensive public participation. End−uses and perceived needs are vital inputs for responsible energy planning.

Renewable energy sources

Given the profiles of energy consumption patterns in urban and rural settlements, it is necessary to examine various primary energy sources in order to introduce new or upgraded technologies for better fuel−efficiency conversion.

The exploitation of renewable energy sources is particularly relevant to the needs of oil−importing developing countries. In order to shift from an oil−based economy to one less dependent on oil and to ensure an adequate and uninterrupted supply of energy to the domestic sector, it will be necessary to consider using all types of renewable energy sources, including solar, wind, biomass, small−scale hydro resources, and decentralized non−oil−based rural electricity generation.

At present, renewable sources of energy are underdeveloped, but their importance at the level of settlements could be quite substantial. At present there are technologies which are viable but are not sufficiently developed for wide−scale use, and technologies which have been fully developed and tested but are still not extensively used. For instance, the use of solar energy in space and water heating is sufficiently well developed for application on a wide scale.

A programme for meeting the energy needs of low−income households would include the creation of effective mechanisms for promoting alternate energy resources and the rational use of commercial fuels.

A decentralized integrated energy system for human settlements

Research and development projects on non−conventional energy sources have, until now, concentrated on developing individual products which would enable solar, wind and other sources of energy to be utilized productively. The emphasis has been on establishing the technical viability of concepts and on testing prototypes to demonstrate that they can work. Briefly, an analysis of the results of the research and development activities undertaken so far show that, while the technical feasibility of many products has been established, it is far from certain that it will be possible to bring their costs down to levels which will make them economically attractive for large−scale usage. In order to solve the energy problems of low−income groups, new strategies emphasizing the rational use of non−commercial alternative energy resources and adopting new technologies are needed.

The development and large−scale introduction of an integrated total energy package can be successfully achieved as part of a national programme with assistance from multilateral organizations. Such a rural energy programme will have to form a part of the total development plan of a region (sub−national), since the energy package can only be one component of the efforts for the development of that region. The varying needs of each region (even in the same country) must be taken into account, and the technological solutions will have to be adapted and modified to suit local needs in each case.

Summary of priority issues on energy and human settlements

It is widely recognized that adequate, reliable and relevant information on energy requirements, primary energy supply and end use, and energy conservation is not available. Systematic national programmes to collect data and statistics on energy in human settlements must be initiated on a priority basis. In order to carry out the work effectively, methodologies for data collection, evaluation, retrieval and updating must be established on a uniform basis so that analysis can be based on comparable data.

Energy conservation

In view of the escalating cost of energy, the present status of relative inefficiencies prevalent in human settlements should be investigated and the potential for energy conservation in the future assessed. The investigation should include:

(a) The potential for energy conservation in heating and cooling existing buildings;

(b) The applicability of bioclimatic design principles in the design of new buildings and planning of neighbourhoods;

(c) The efficiencies of converting fossil fuels into electricity;

(d) The transmission losses in carrying electricity from central power generation grids to remote settlements';

(e) The conversion efficiencies of the so−called non−commercial fuels used in domestic, agricultural and small−scale industrial sectors;

(f) The options for energy substitution in performing various functional tasks with a view to conserving non−renewable energy resources;

(g) The deficiencies of and potentials for improvements in various modes of transportation used in urban and rural settlements.

Studies on domestic energy pricing

In most developing countries, there is a poor understanding of energy pricing. In view of the important contribution of non−commerical fuels to the rural domestic energy sector and the present energy policies (kerosene, rural electrification, subsidies) of some developing countries, pricing for such fuels, particularly those used by low−income groups in rural and urban settlements, must be investigated. Topics requiring study include:

(a) The kerosene subsidy provided by Governments and its impact on the overall energy import and balance−of−payments situation;

(b) The crucial role of kerosene in current pricing policies and in relation to the increasing scarcity of non−commercial fuels;

(c) The direct and indirect subsidies included in rural electrification programmes;

(d) The impact of energy price changes on the domestic consumption patterns of various income groups, in particular on the low−income groups;

(e) The social costs of the collection of non−commercial fuels.

Assessment of available renewable sources of energy

Surveys are needed in every developing country to establish the potential of locally available renewable sources of energy which can be harnessed to meet the needs of rural and urban settlements. These should include:

(a) Evaluating the potential of small streams and canals for the application of water−mills;

(b) Assessment of the growth potential of various types of fast−growing shrubs and trees for the establishment of plantations as energy sources for rural settlements;

(c) Collection and analysis of wind data for assessing the potentials of windmill use in rural areas;

(d) Collection of solar data.

Integrated energy systems

Given the subsistence levels of domestic energy consumption in rural settlements and of the urban poor, any new energy policies and plans to increase the energy base should emphasize the rational use of non−commercial fuels and the adoption of new technologies to maximize the benefits derived from harnessing renewable energy sources. An integrated approach involving the exploitation of all potential, locally available energy resources would not only optimize the benefits that could be obtained from renewable energy sources but also ensure an uninterrupted supply of energy to meet the needs of the domestic, agricultural and small−scale industrial sectors of rural settlements.

Rural electrification and rural energy programmes

In order to establish optimal energy systems for rural settlements, an in−depth analysis of rural electrification programmes should be made to establish their economies and limits as well as their possibilities in a variety of settlement contexts. Such studies will be required for each country to establish guidelines for creating various energy−supply zones and should determine:

(a) Zones which will be supplied from central power stations;

(b) The role of supplementary energy supply from renewable sources within those zones covered by central power stations (both for rural and urban settlements);

(c) Zones for decentralized small power stations based on conventional energy sources;

(d) The role of non−conventional energy in those zones;

(e) The zones of decentralized total energy packages.

Based on such studies, it will be possible to build up a matrix of energy supplies and end−uses on a regional basis in each country. The matrix can then be used to ensure that human settlements will begin to get an optimal supply of energy within a planned time of allocation.

Pilot and demonstration studies

There are already a large number of promising ways in which the basic energy requirements of urban and rural settlements can be met. It seems desirable to initiate pilot and demonstration projects in a variety of settlement conditions to obtain field data on technological, socio−economic and operational/management problems which must be solved for successful, large−scale application. Machinery to ensure exchange of data and information between various projects, and the full involvement of local communities will also have to be established.

Energy−oriented settlements criteria

In order to provide the methodologies for planning human settlements with adequate attention to energy requirements and conservation, it is essential that a planning criterion embodying energy requirements be developed for various types of climatic, social and economic areas upon which special attention should be focused in the planning of human settlements to ensure the success of energy conservation.

Such studies and programmes could be carried out jointly by the United Nations Centre for Human Settlements (Habitat) and the national and international institutions and organizations concerned. UNCHS (Habitat) could provide the links, such as methodologies, characteristic values for housing, conservation data and other design and cost information, and the national institutions could provide the information relating to local conditions, including socio−economic considerations. Cost estimates could then be obtained, and some of the promising solutions put into effect to demonstrate that such energy−oriented low−income rural and urban settlements are practicable.

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UNITED NATIONS CENTRE FOR HUMAN SETTLEMENTS (HABITAT)
P O Box 33030, NAIROBI