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The Possible Share of Soft/Decentralized Renewables in Meeting the Future Energy Demands of Developing Regions

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FOREWORD

At present the global supply of commercial energy is largely based on fossil fuels and centralized supply systems. However, we now realize that the world's resources of fossil fuels, particularly those of cheap oil and gas, are being depleted, and, moreover, that continued reliance on them may interfere with the globe's climate through the greenhouse effect associated with the increased carbon dioxide concentration in the atmosphere. These realizations force us to consider shifting our energy supply gradually from fossil fuels to renewable and nuclear sources.

Among the renewable sources of energy, large-scale hydropower is already playing a significant role as a centralized source of electricity generation in both the developed and the developing countries. The use of this technology will certainly increase in the coming decades. Other centralized renewable energy supply systems for generating power and producing liquid and gaseous fuels, based on advanced technologies (such as solar–thermal–electric conversion, solar thermolysis, photovoltaic conversion, or interconnected chains of large windmills) have still to cross technological and/or economic feasibility thresholds. They can, therefore, be considered at best as promising major technologies for the long-term future.

However, some decentralized energy supply systems (such as direct or indirect solar energy) and large-scale biomass energy harvesting can possibly make contributions in the less distant future.

In view of the expected future expansion of their infrastructure for both energy consumption and supply, the developing countries offer a favorable environment for adopting renewable sources of energy on the basis of soft and decentralized technologies. However, one wonders what plausible maximum contribution these renewables could make to future commercial energy supplies that would be consistent with socioeconomic development and avoid undue hardships.

The work described in this report was undertaken in order to arrive at realistic assessments of the contributions of soft/decentralized renewable energy sources in the light of the energy demands projected for the market-economy developing world regions in the High and Low scenarios generated in the IIASA Energy Systems Program. Further information about these scenarios and the analysis of which they are a part has been published by the Energy Systems Program Group of IIASA (1981) in *Energy in a Finite World*: Volume 1, *Paths to a Sustainable Future*; Volume 2, *A Global Systems Analysis* (Cambridge, MA: Ballinger).

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SUMMARY

The consumption of commercial energy in the developing countries is expected to increase by a factor of about 10 over the next 50 years. As most of the infrastructure related to their energy consumption and supply will undergo a major expansion during the next few decades, it should be possible to introduce soft/decentralized technologies based on renewable sources of energy in order to meet a significant fraction of the future energy demand in these countries. This report assesses what could, under favorable conditions, be a maximum share of soft/decentralized renewables in meeting the future commercial energy demand of the three market-economy developing world regions considered in the global energy study of the IIASA Energy Systems Program (Region IV: Latin America (LA); Region V: Africa (except Northern Africa and South Africa) and South and Southeast Asia (Af/SEA); Region VI: Middle East and Northern Africa (ME/NAf)).

A number of soft/decentralized technologies based on renewable sources of energy are looked into and their investment requirements (per unit capacity) and fuel production costs are compared with those of conventional supply schemes. Shortcomings and practical difficulties associated with some of these technologies that render them unsuitable for meeting different categories of demand in rural areas and in small and large urban centers are analyzed. It is concluded that the most promising soft/decentralized renewables are: windmills and small hydropower units for use in irrigation and for supplying electricity to rural households and small towns; charcoal for meeting thermal energy requirements of industry, households, and the service sector; biogas for use in rural households; and solar heat for supplying hot water/steam to industries, households, and services. Maximum feasible shares of soft/decentralized renewables to meet different categories of demand by 2000 and 2030 are stated. The quantities of energy to be supplied by different technologies are estimated by superimposing these shares on the sectoral and subsectoral demands for electricity and useful thermal energy as projected in the High and Low scenarios of the IIASA study.

The shares of soft/decentralized renewables in the commercial final energy demand of the three developing regions in 2030 are estimated to be about 7% for electricity, 17% for nonelectric energy (charcoal 15%, biogas 1%, soft solar 1%), and 15% for total final energy. The soft/decentralized renewables will be required in 2030 to supply 0.7–1.1 TWyr of final energy, which is large in relation to the commercial final energy demand of 0.6 TWyr in 1975 in the three regions.

Soft/decentralized renewables will be of greatest importance in rural areas. With the continuing use of noncommercial fuels in the rural areas of the three regions to satisfy about 60% of their thermal energy requirements, the commercialized soft/decentralized renewables are projected to meet about 35% of the electricity demand and 22% of the nonelectric commercial final energy demand of the rural sector in 2030. For the urban sector, it is estimated that by 2030 soft/decentralized renewables may be invoked to cover about 15% of the electricity demand and about 17% of the nonelectric demand originating from small urban centers.

Among the soft/decentralized renewables charcoal stands out as the most important and, at the same time, the most difficult component of the future supply schemes. In Region IV(LA), a region with large forest resources, the projected High scenario demand for charcoal in 2030 may be met by utilizing about one-third of the annual regenerative capacity of the region's natural forests. However, the same is not true for Regions V and VI (Af/SEA, ME/NAf). If it is assumed that not more than about one-third of a region's natural forest may be harvested for energy purposes, Region V will be required by 2030 to raise energy plantations over an area equivalent to about 10% of its present arable land in order to meet its High scenario demand for charcoal. The situation will be even more critical in Region VI, whose natural forest resources are extremely small. This region will have to undertake extensive energy plantation operations to meet its demand for charcoal in both scenarios. The area required to be put under plantations by 2030 is estimated, in the High scenario, to be about the same as the region's present arable area.

This assessment of the possible role of soft/decentralized renewables is based on optimistic assumptions. The envisaged supply of energy by these renewables can certainly be met if a well organized, large effort is initiated by the developing regions without loss of time, and pursued vigorously for the next 50 years. Any further delay or halfhearted effort would result in a smaller contribution by soft/decentralized renewables than is anticipated here.

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1 INTRODUCTION

The developing world regions considered in this report are only those comprising market-economy countries and are defined as Regions IV, V, and VI in the IIASA study (Energy Systems Program Group of IIASA 1981). Region IV is Latin America (LA); Region V is Africa (excluding Northern Africa and South Africa) and South and Southeast Asia (Af/SEA); and Region VI is the Middle East and Northern Africa (ME/NAf). The countries in each region are listed in the Appendix.

The consumption of primary commercial energy in these regions in 1975 amounted to 0.80 TWyr yr^{-1}. According to the two IIASA scenarios, corresponding to different projected levels of economic growth, the consumption will increase to about 8–13 times its 1975 value by 2030. As most of the infrastructure related to energy consumption and supply in the developing countries will be established over the next 50 years, it is worth while to explore the extent to which soft/decentralized technologies based on renewable sources of energy may be called upon to meet the future energy demand in these regions. To do this we shall make a brief survey of such technologies that hold promise of wide-scale application in the developing regions; identify the plausible extent of their application to different energy-consuming activities; and then estimate their contribution to meeting the energy demand projected in the two IIASA scenarios for the years 2000 and 2030, assuming that an aggressive policy were to be pursued in favor of soft/decentralized renewables. Finally, we shall consider how such an assessment stands in relation to the resource base of renewables in the three developing regions.

In the context of this paper renewable energy sources are solar energy, wind, hydropower, biomass, geothermal energy, etc. They will frequently be referred to as "renewables." The term "soft" refers to simple technologies such as harvesting of wood from forests and plantations and use of small-scale hydropower, whereas the term "decentralized" implies localized systems, e.g. windmills, small hydropower units, and biogas plants that are not part of centralized supply systems. Large windmills may not be called soft technologies but are still decentralized technologies, whereas wood harvesting may involve a very large organized effort but is still considered here as a soft technology. The technologies included in this assessment are not necessarily "soft" and "decentralized" at the same time, but they belong to at least one of the categories. Centralized supply schemes using relatively advanced technology, such as hydropower plants, interconnected chains of windmills, and solar–thermal–electric conversion, are therefore not considered here. The soft/decentralized technologies based on renewable sources of energy will often be referred to as "S/D renewables."

2 SOME BACKGROUND INFORMATION

In 1975 the developing countries of Africa, Asia, and Latin America had a population of 1874 million, 30% of whom lived in urban areas and 70% in rural areas (United Nations 1976). The main sources of income in rural areas are activities such as agriculture, fishing, and cattle breeding. Most of these activities, in particular farming, are still carried out by way of centuries-old traditional practices requiring intensive use of human labor and draft power. However, the pressure caused by increasing population, limited resources of arable land (0.34 ha per capita in 1975, as against 0.62 ha in the developed regions (Food and Agriculture Organization 1977)), and inadequate supplies of water from precipitation and canals is gradually forcing a change toward more productive, mechanized methods of both farming and irrigation.

At present there is little industrial activity in the rural areas although efforts are being made by various governments to establish handicraft and cottage industries to reduce the population shift to urban areas. Most of the villages have a few hundred inhabitants and are distributed close to the arable land. The facilities of electricity and transportation are generally inadequate. According to a survey by the World Bank in 1975 only about one-sixth of the total rural population of the developing countries (4%

in Africa, 15% in Asia, and 23% in Latin America) had access to electricity. The present trend of rural electrification seems to be dominated by extending grid supplies to rural areas rather than by establishing independent, small generating units.

About 60% of the urban population in the developing regions was concentrated in 1975 in cities of 100,000 or more inhabitants (UN 1976). Although all urban dwellers have potential access to electricity, a large fraction of the poor do not have the financial resources to cover the initial cost of electrification and are still without electricity. A substantial fraction of the electrified households use electricity only for lighting and for operating ceiling fans, radios, and television sets.

The requirements of nonelectric energy in both rural and urban households are dominated by cooking needs. This is because about three-quarters of the population live in areas where hardly any space heating is required in winter and the use of hot water is also minimal, in general. Noncommercial fuels to the extent of 0.5 TWyr were used in 1975 mainly for cooking and heating in households. Understandably the share of noncommercial fuels in meeting the household requirements is much higher in rural than in urban areas. It is generally estimated that the efficiency of noncommercial fuels, as they are presently used, is only 5–10%, compared with 30–60% for fossil fuels. Thus the present level of use of noncommercial fuels serves requirements that could perhaps be met by some 50–100 GWyr of fossil fuels.

The manufacturing activities are practically all confined to urban areas. They are generally based on processes and technologies similar to those that either are presently used in the developed countries or were used by them within the last few decades. The mining and construction operations are, in general, very labor-intensive (except for oil and gas mining), although mechanization is gradually being increased.

Things will change considerably in the next 50 years. In particular there will be much progress in industrial activity coupled with an increased level of urbanization. The rural development programs will help provide electricity to a large fraction of the rural population. Agriculture, construction, and mining activities will also become much more mechanized. In view of the growing scarcity of fossil fuels the renewable forms of energy will certainly have a role in various sectoral activities but this role will vary from sector to sector and will not be the same for all groups of the population. For example, cities with populations of millions will almost exclusively have to rely on centralized electricity grids, whereas it may be economically attractive to supply electricity to scattered and remote villages and to irrigation water pumps in certain areas from windmills and small hydropower units. For a proper assessment of the role of soft/decentralized renewables one therefore needs to look into the distribution of future energy demand among the sectoral activities as well as among various groups of the population.

3 PROMISING SOFT/DECENTRALIZED TECHNOLOGIES

The developing world regions have a large potential of renewable energy sources. For example, the annual increment of wood above ground in the regions' forests is equivalent to about 7 billion tonnes (7×10^9 t) of dry wood with an energy content of about 4 TWyr (Earl 1975, FAO 1977). The energy content of agricultural and animal wastes produced at present in these regions is estimated to be about 0.4 TWyr yr^{-1} (FAO 1977, Parikh 1978, Revelle 1979). This will probably increase by a factor of 3–5 over the next 50 years. The total hydropotential in the developing regions corresponds to about 0.5 TW(e)yr yr^{-1}, of which only about 6% is in use at present, and that mostly through centralized generating schemes (UN 1977, World Energy Conference 1978). There is an abundance of sunshine in most of the regions, with an average solar irradiance of 1500–2000 kWh m^{-2} yr^{-1}. Winds having useful velocities are also found near coastal areas at distances of up to several hundred kilometers from the coastlines. As a rough estimate, the realizable potential of mechanical power from wind available in the developing regions may be taken as 0.5 TWyr yr^{-1}. The realizable potential of wet geothermal energy would also correspond to about 0.5 TWyr yr^{-1}. These potentials of wind power and geothermal energy assumed for the developing regions are half of those estimated for the world as a whole (Energy Systems Program Group of IIASA 1981).

In spite of their large potential the only significant applications, so far, of renewable sources of energy in the developing regions have been centralized hydropower generation and use of noncommercial fuels derived from disorganized cutting of forests and from agricultural and animal wastes. Recently some countries (most notably India) have started promoting the use of biogas plants in rural areas, while Brazil has embarked on a program of production of alcohol from sugarcane for use as fuel. Other applications such as those of windmills, small hydropower units, soft solar devices, and plantation schemes, are lagging further behind and are still in the exploratory stages.

Since the various soft/decentralized technologies have not been commercialized it is not possible to make firm estimates of their investment requirements or fuel production costs. In addition, both the investment requirement per unit of installed capacity and the total cost per unit of energy produced will vary considerably for each technology, depending on the geography, environmental conditions, and indigenous industrial capability. Nevertheless some rough estimates are necessary in order to identify the technologies that hold promise of large-scale utilization in areas where resource conditions are favorable.

Table 1 presents some estimates (in 1975 US dollars) of the capital costs (per unit peak capacity) and the average energy production costs of S/D renewables for electricity generation. The estimates of capital costs are, in general, based on the prices of basic equipment now commercially available in some countries. The cost of electricity production has been calculated by fixing a charge of 10% per annum on capital cost and using the appropriate duty cycle in column 4. The table also allows a comparison of the S/D renewables with conventional centralized systems.

As centralized systems of electricity supply also entail large investments in transmission networks and have associated maintenance and distribution expenses, the actual energy supply costs from centralized systems would be some 50–100% higher than those in Table 1. Thus under favorable conditions the supply from individual windmills and small hydropower units may be more economical. The cost of electricity production from photovoltaic arrays is, however, an order of magnitude too high at present. It is too early to say whether the cost can be reduced sufficiently to make such systems an economically attractive proposition within the next 50 years.

Although windmills and some small hydropower units appear economically competitive with centralized power generation in terms of supply cost per unit of electricity, their energy sources are irregular by nature. This shortcoming makes them unsuitable for supplying regulated power to large cities, major industries, and electrified transportation systems.

TABLE 1 Electricity supply from S/D renewables: estimates of capital costs and electricity production costs, and comparison with centralized systems.

Technology	Capacity	Capital cost[a] (1975$ kW(e)$^{-1}$)	Assumed duty cycle (h yr^{-1})	Electricity cost[b] (1975$ kW(e)h^{-1})
Windmills	< 1 kW(e)	3000–6000	2500	0.12–0.24
	5–15 kW(e)	1000–2000	2500	0.04–0.08
	3 MW(e)[c]	450	2500	0.02
Small hydropower units	0.5–10 kW(e)	1000–7000	4000	0.03–0.18
Photovoltaic devices	< 1 kW(e)	15,000–30,000	2000	0.75–1.50
Centralized systems				
Large hydropower units	250 MW(e)	800–1500	4000	0.02–0.04
Coal-fired plants	300 MW(e)	500	4000	0.02
Oil-fired plants	300 MW(e)	400	4000	0.03

[a] These estimates are based essentially on the information given by the National Academy of Sciences (1976), WEC (1978), Cecelski *et al.* (1979), and the Energy Systems Program Group of IIASA (1981).
[b] These costs have been worked out by assuming a fixed charge of 10% per annum on capital investment and neglecting the operating costs. For coal- and oil-fired plants an allowance has also been made for the fuel cost at 25$ ton^{-1} for coal and 12$ bbl^{-1} for oil.
[c] Large windmills with capacities in the MW(e) range are in the development stage.

However, this unsteady nature would not pose much of a problem in meeting irrigation water-pumping requirements. Similarly, villages and small towns might tolerate to a considerable extent an irregular electricity supply and could meet part of their requirements from diesel-operated systems or central grids. However, the use of windmills and small hydropower units would call for considerable investments ($2000–10,000 per kW(e)yr yr^{-1} of supply), which may be difficult for individuals or small groups to afford without government finances.

Table 2 lists the capital costs (per unit peak thermal capacity) and the average energy production costs of some solar devices, biogas plants, and alcohol production plants. The simple solar devices considered for water heating, space heating, and cooking are made from reflecting material that costs about $100 per m^2 of surface. The biogas plants are the one-family and community units of the Indian design discussed by Parikh (1978). The capital cost for alcohol production was estimated by Goldemberg (1979) and corresponds to the Brazilian situation. The energy costs in column 4 (expressed per unit of useful energy for solar devices and of energy content of fuel for other plants) are, again, based simply on a fixed charge of 10% per annum on capital cost and the assumed duty cycle in column 3. Also listed in Table 2 are the production costs for fuelwood and charcoal estimated by Earl (1975) for two different schemes in East Africa: harvesting natural forests, and raising energy plantations. Unlike the energy costs of solar heating, biogas, and alcohol, which have been worked out by neglecting the operating costs (although they would not be negligible for large biogas and alcohol plants), the costs of fuelwood and charcoal include both the royalty paid on the forest/land area used and the operating costs. For comparison the energy costs of coal and of oil are also shown, but the actual price paid by the user for coal and oil will, in general, be much higher when taxes, profits, and transportation are taken into account.

TABLE 2 Thermal energy supply from S/D renewables: estimates of capital costs and energy production costs.

Technology	Capital cost[a] (1975$ kW^{-1})	Assumed duty cycle (h yr^{-1})	Energy cost[b] (10^{-3} $ kWh^{-1})
Solar water heating	300–600	2000	15–30
Solar space heating	400–800	500	80–160
Solar cooking	200–300	500	40–60
Biogas:			
one-family units	500	Continuous	6
community plants	250	Continuous	3
Alcohol production from sugarcane	800	4000	20
Fuelwood production:			
harvesting natural forests			0.3
energy plantations		–	0.4–0.7
Charcoal production:			
harvesting natural forests		–	1.2
energy plantations		–	1.8–2.5
For comparison			
Coal at 25$ ton^{-1}		–	3
Oil at 12$ bbl^{-1}		–	7

[a]These estimates are based essentially on the information given by NAS (1976), WEC (1978), Parikh (1978), and Goldemberg (1979).

[b]Except for fuelwood and charcoal, the energy costs reflect only the contribution of capital costs at a fixed charge of 10% per annum. The cost estimates for fuelwood and charcoal are based on the data given by Earl (1975).

To the extent that one can rely on the estimates in Table 2, renewable energy supply schemes based on biogas plants, energy plantations, and harvesting of natural forests appear attractive when their energy production costs are compared with the prices of coal and oil in the international market. Alcohol production may become more economical in coming years, as coal and oil prices rise. The energy costs for solar devices are relatively high but may fall as a result of the current R&D effort and the possible introduction of mass production. In any case the relative energy costs of different solar devices will remain roughly in the same proportion as in Table 2; in particular, solar water heating will remain more attractive than solar space heating. Very simple solar cookers, costing as little as $15 each, were produced in India in the 1960s but failed to be accepted in rural areas even though the government gave financial support to popularize them (Cecelski *et al.* 1979). The experience in other countries has not been very different. This is understandable because solar cookers are very inconvenient for the housewife, and the time when they may be used efficiently does not coincide with the time when most people want to have warm meals. Therefore, we do not expect much success for solar cookers (in spite of lowered production costs) as long as more convenient means of energy supply for cooking remain available at acceptable costs. These alternatives for rural areas, which may be considered the most likely environment for using solar cookers, are fuelwood, agricultural and animal wastes, and biogas.

Biogas generation offers a very efficient and convenient form of fuel but its application is limited to rural areas. In view of the relatively low investment potential of families in villages it is to be expected that large plants for the community, perhaps built with the help of external financing, will be much more successful than the smaller, one-family units. While envisaging the application of biogas plants one should keep in mind the traditional social customs and habits of people in the handling of animal wastes. Taking into account these considerations and the relative availability of forest wood in different developing regions, we feel that the biogas plants will not have much success in the rural areas of Latin America. On the other hand, they may be very successful in the villages of Africa and Asia provided that the necessary investment funds are made available.

In order to consider the long-term prospects of supplying wood/charcoal from natural forests and energy plantations and of producing alcohol from sugarcane or other crops, one should look at the present land utilization patterns in developing regions. Table 3 shows that there are about one billion hectares of forest area in each of Regions IV and V whereas Region VI has a meager 28 million hectares of woodland. Although the indiscriminate cutting of forests in recent years, particularly in Africa and Southeast Asia, has been causing serious deforestation and land erosion, silviculturally sound practices may allow harvesting of large amounts of wood from natural forests without adverse effects, and perhaps even with beneficial effects (Earl 1975).

Both of the other alternatives (energy plantations and alcohol production from sugarcane or other similar crops) are to be seen in competition with the requirements of food production for a growing population. The availability of arable land in Regions IV, V, and VI in 1975 was only 0.45, 0.32, and 0.33 ha per capita, respectively. These figures appear low when compared with 0.62 ha per capita, the average area of arable land available in the developed world regions. There does not appear to be much prospect for expanding arable land in the developing regions, so the per capita availability of good agricultural land in these regions will become even smaller in the next 50 years, over which period the population will increase to about 2.5 times the present number. The production of sugarcane, or of similar crops, requires good agricultural land with an adequate water supply. (The cultivated area of sugarcane required to produce 1 $GWyr\,yr^{-1}$ of alcohol in Brazil was estimated by Goldemberg (1979) to be 0.4×10^6 ha.) It is unlikely that the production of alcohol from agricultural crops will be able to play any significant role in the long run,

TABLE 3 Distribution, by region, of population and land in 1975. Arable land includes the area under permanent crops. Source: FAO (1977).

Region	Population (10^6)	Arable land (10^6 ha)	Permanent pastures (10^6 ha)	Forests and woodland (10^6 ha)	Other land (10^6 ha)	Total land (10^6 ha)
IV	319	142	527	1071	374	2114
V	1422	456	710	963	1074	3203
Africa	319	184	671	633	840	2328
Asia	1103	272	39	330	234	875
VI	133	45	172	28	802	1047
Africa	57	13	45	3	453	514
Asia	76	32	127	25	349	533

when there will be great pressure to use such land for producing food. On the other hand, energy plantations based on certain species of fast-growing trees can be raised on marginal agricultural land (Earl 1975) and, as such, do not necessarily interfere with food production requirements. Raising such plantations would help to control land erosion in certain areas and may even be a welcome approach in the neighborhood of populated areas far from natural forests.

Although wood can be used directly as fuel it is not as convenient to handle and transport as charcoal and burns with a lower efficiency (for supplying useful energy). It is therefore expected that most of the available wood from forests and plantations will be converted to charcoal for use in industry and urban households. The additional expenditure incurred in conversion of wood to charcoal and the conversion energy losses (equivalent to about 50% of the energy content of wood) will then be more or less counterbalanced by the savings in transportation expenses and the higher burning efficiency of charcoal.

In principle, wood and its associated tree matter (leaves and twigs) can also be used to obtain liquid or gaseous fuel but no proper cost estimates are available for such an operation at a sizable scale. In general one would expect the investment per unit capacity of liquid/gaseous fuel to be much higher for this operation than for production of alcohol from sugarcane. Therefore we do not consider this as a viable alternative to charcoal production.

The use of wood/charcoal for electricity generation at a decentralized level is not considered here as the capital costs (per unit capacity) of small thermal power plants will be too high to make them economically viable. Large thermal power plants (of the order of 100 MW(e)) may be more economical but they will also be more complex systems and will need to be linked to central grids; therefore, they cannot be considered as either a soft or a decentralized technology. In any case it would be preferable to use the available wood/charcoal for direct thermal uses rather than for power generation if the demand for the former use alone is sufficient to put a great pressure on the resources of natural forests. (We shall show that this situation will apply to the three developing regions if the use of S/D renewables is promoted to the extent envisaged in the present assessment.)

The costs of supplying energy from wet geothermal sources are not mentioned in Table 2 as these sources are limited to only a few locations, and hence are unsuitable for wide-scale decentralized use; moreover, the costs will depend very much upon location.

For the reasons given above, we view only four soft/decentralized technologies based on renewables as holding promise for wide application to developing world regions over the next 50 years.

(i) *Windmills, small hydropower units*: for irrigation water pumping and supplying electricity to villages and small towns.

(ii) *Charcoal*: for industry, households, and the service sector, mainly as a source of thermal energy.

(iii) *Biogas*: for rural areas of Africa and Asia, where the handling of animal wastes is traditionally and culturally acceptable.

(iv) *Solar heat*: mainly for supplying hot water/steam to industries and hot water to households and services; of limited use for space heating (in rich households and the service sector where the availability of capital is not a problem).

4 SCENARIO ASSUMPTIONS CONCERNING USE OF SOFT/DECENTRALIZED RENEWABLES

Many factors will determine the extent to which soft/decentralized technologies based on renewable energy sources may be invoked to meet the future energy demand. The most important of these are listed below:

- the cost economics of S/D renewables as compared with those of conventional forms of energy;
- the magnitude of the domestic resources of conventional fuels;
- the production potential of renewables close to demand centers;
- the convenience of use and social preferences;
- the access of different sections of the population to central power grids;
- the investment potential of individuals and small groups for financing independent installations;
- the government loan and investment policies for funding decentralized supply sources in preference to centralized facilities; and
- the problems of institutional changes and management.

All these factors will vary from region to region and much more so from country to country. A detailed analysis that acknowledges so many factors with their inherent uncertainties may prove to be a formidable task. Therefore, we shall make some simplifying assumptions that allow us to estimate the possible share of S/D renewables in meeting the future energy demands of the developing countries.

4.1 General Assumptions

(1) In view of the general scarcity of fossil fuels and the high cost of electricity transmission through centralized grids to small towns and rural areas, vigorous efforts will be made to make increasing use of renewables on a soft/decentralized basis. The institutional, managerial, and financial problems will be overcome through national policies and governmental support.
(2) The electricity requirements of *cities* (large urban agglomerations each with 100,000 or more inhabitants) will be met solely through centralized supply schemes, whereas those of *towns* (urban agglomerations having up to 100,000 inhabitants) and *villages* (covering all rural households) will be met partly by S/D renewable sources. It is assumed that half of the towns and villages will be in areas where renewable sources may be used for electricity generation on a decentralized level. In view of the variable nature of these sources (wind, small-scale hydropower), the problems of energy storage, and the need for diversification of power sources, it is further assumed that of the power requirements in such areas not more than 60% in villages and 30% in towns can actually be supplied by S/D renewables.
(3) The decentralized renewable sources of power will be available in areas covering about half of the agricultural land that will require irrigation by pumping of water. As the demand for irrigation is more flexible than the needs of households, services, and industries, it is assumed that up to 80% of the requirements in favorable areas can be supplied

by decentralized renewables. It is also assumed that the other power needs of the agricultural sector (e.g. for grinding grain) can be met by S/D renewables to the same extent.
(4) The main manufacturing industries will all be in urban areas only and distributed between cities and towns in proportion to their respective populations. The small power requirements of cottage industries in villages will be included in the electricity demand of the rural households.
(5) Rural electrification will increase rapidly in all developing regions and will be complete within the next 50 years. The consumption of electricity will be the same in a village household as in an urban household of the same region. Although this amounts to overemphasizing the share of rural households in electricity consumption, it may be justified by assumption (4).
(6) The energy-consuming activities of the service sector will be confined to urban areas and distributed between cities and towns in proportion to population.
(7) It will not be possible to meet the electricity requirements of the mining, transportation, and construction activities with S/D renewables to any significant extent.
(8) Although, in principle, all the useful thermal energy demand of the household/service sector and most of the industrial demand may be considered potentially suitable for S/D renewables, in practice it will not be possible to make use of these renewables to such an extreme. For example, rich households, sophisticated service establishments, and certain large modern industries will in all likelihood continue to make use of relatively more convenient and clean forms of conventional fuels. The reliance of industries upon fossil fuels for certain uses will also be dictated by specific processes, e.g. those requiring high-temperature furnace heat. Therefore, we shall make the following assumptions.

- (i) In the industrial sector, up to 80% of the hot-water/low-temperature steam requirements, 60% of the high-temperature steam requirements as well as coke needs of the steel industry, and 12% of the high-temperature furnace heat requirements may be met by S/D renewables.
- (ii) In the household sector, the S/D renewables may be invoked to meet, in combination with noncommercial fuels, as much as 90% of the useful thermal energy requirements (for cooking, water heating, space heating) in villages, 80% in towns, and 60% in cities.
- (iii) In the service sector, the share of S/D renewables in meeting the useful energy demand (for water and space heating) may be as large as 60% for towns and 40% for cities.

(9) S/D renewables will not be used to any significant extent to produce liquid fuels. Since practically all the nonelectric demand of transportation, mining, construction, and agricultural activities will be for liquid fuels, the S/D renewables will not be required in any significant amount to meet it. (The gas used in petroleum-mining activities cannot be replaced by renewables either.) Similarly, the use of fossil oil in the production of petrochemical feedstocks will not be replaced by S/D renewables.
(10) The use of S/D renewables will proceed so that by 2030 their share in meeting the energy demand for various sectoral activities will be as high as anticipated in these assumptions.

4.2 Additional Assumptions Concerning Specific Renewables

(A) The use of noncommercial fuels was increasing in the past. It is assumed that, as a result of efforts to organize harvesting of wood from forests and to introduce biogas plants in rural areas, the total quantity of noncommercial fuels used (user-collected firewood, agricultural and animal wastes) will stay about the same as in 1975 in each region. Further, efforts will be made to introduce devices that will help to improve the efficiency of use of noncommercial fuels, by 2030, to 1.6 times its 1975 value in each of Regions V and VI, and to 2.0 times its 1975 value in Region IV. It is also assumed that noncommercial fuels will be used mostly in villages and that the balance, if available, will be used in the households of small towns.

(B) Extensive use will be made of biogas plants in the rural areas of Regions V and VI. By 2030, 90% of the nonelectric energy demand from village households will be allocated to renewables; the part that is not met by noncommercial fuels will be supplied by biogas generation. The efficiency of burning biogas will be the same as that of natural gas.

(C) Soft solar devices for water heating, space heating, and steam generation will find increasing use after the turn of the century. It is assumed that by 2030 such devices, backed by 20% fossil fuel support, will be used to meet:

- (i) 30% of the hot-water/low-temperature steam requirements and 10% of the high-temperature steam demand of industries in all regions;
- (ii) 30% of the hot-water demand in households of Regions IV and V (15% in Region VI);
- (iii) 50% of the space-heating demand of centrally heated, single-family houses in Region IV and 20% of this demand in Region VI; and
- (iv) 50% of the heat requirements of low-rise buildings of the service sector in Regions IV and V (20% in Region VI).

(D) All wood supplied commercially will be converted to charcoal. The efficiency of charcoal for different uses will be the same as the average fossil fuel efficiency for corresponding applications.

5 FUTURE DEMANDS FOR SOFT/DECENTRALIZED RENEWABLE ENERGY

The assumptions of Section 4 provide a general framework for estimating the possible overall contribution of S/D renewables to satisfying the future energy demands of the developing regions. It has been assumed that by 2030 S/D renewables in two groups (as sources of electric and nonelectric energy) will penetrate their respective markets covering various sectoral activities to the maximum extent feasible in our judgment. The projected penetrations are listed in Tables 4 and 5. Also listed are appropriate figures for the year 2000, in line with the projected penetrations for 2030. Relatively high penetrations are assumed for nonelectric energy demand in 2000 (Table 5) compared with those for electric energy demand (Table 4). This is because: (i) we feel that it would not be too difficult for industries and the household/service sector to shift from fossil fuels to charcoal if appropriate policy measures were adopted soon enough on a national basis; (ii) the industrial

TABLE 4 Projected penetrations of decentralized renewable sources of energy in the electricity supply schemes of developing regions (expressed as a percentage of electricity demand). Only 60% of the village households in Region IV and 50% in each of Regions V and VI are assumed to have access to electricity in the year 2000.

Demand sector	2000	2030
Households		
Cities	–	–
Towns	2.5	15.0
Villages	5.0	30.0
Service sector		
Cities		–
Towns	2.5	15.0
Manufacturing		
Cities		–
Towns	2.5	15.0
Agriculture	7.5	40.0
Other sectors		
Transport, mining, construction	–	

TABLE 5 Projected penetrations of soft renewable sources of energy in the nonelectric energy supply schemes of developing regions (expressed as a percentage of useful energy demand). Penetration of soft renewables in the household sector includes use of noncommercial fuels.

Demand sector	Nature of demand	2000			2030
		Region IV (LA)	Region V (Af/SEA)	Region VI (ME/NAf)	Regions IV, V, VI
Households					
Cities	Cooking, space heating, water heating	40	45	20	60
Towns	Cooking, space heating, water heating	60	70	40	80
Villages	Cooking, space heating, water heating	75	85	60	90
Service sector					
Cities	Space heating, water heating	20	20	20	40
Towns	Space heating, water heating	30	30	30	60
			Regions IV, V, VI		
Manufacturing					
	Low-temperature steam/ hot water		40		80
	High-temperature steam		30		60
	Furnace heat		6		12
	Steel industry (coke replacement)		30		60
	Feedstocks (oil replacement)		–		–
Other sectors					
Transport, agriculture, construction, mining	Mainly liquid fuel demand		–		–

infrastructure is still being established in the developing regions and this favors rapid penetration of renewables in the industrial sector if a number of new industries opt for them; and (iii) renewables, in the form of noncommercial energy, were already supplying in 1975 about 40, 70, and 10% of the useful thermal energy requirements of households (urban and rural) in Regions IV, V, and VI, respectively. The penetrations of S/D renewables in the nonelectric energy demand of households (Table 5) include the use of commercial and noncommercial forms of renewable energy and should, therefore, be considered in relation to the present situation.

There are some additional assumptions for the year 2000 not explicitly covered in Section 4.

(*a*) The fractional uses of soft solar energy for various activities will be a factor of about 2–10 lower than those in 2030.

(*b*) The efficiency in using noncommercial fuels will be only about 15–20% higher than that in 1975.

(*c*) Biogas will be used to supply only 50% of the fraction of the nonelectric energy demand of rural households that is allocated to renewables but not met by noncommercial fuels.

(*d*) Electrification will extend to 60% of the villages in Region IV and 50% of those in Regions V and VI.

To make quantitative estimates of the requirements of soft/decentralized forms of renewable energy in 2000 and 2030, we need the corresponding projections for (i) the population distribution among cities, towns, and villages, and (ii) the sectoral requirements of electricity and useful thermal energy for various activities. The projections for population distribution are given in Table 6 together with the historical data for 1950 and 1975. For the year 2000, the estimates of rural/urban distribution are based on UN (1976) projections, whereas those for the distribution of urban population between cities and towns are extrapolations of the UN projections for 1985 (UN 1976). All the estimates for 2030 are our own, made by extrapolating the historical data and the available UN projections.

TABLE 6 Distribution of population (%) in cities, towns, and villages: historical data and projections. Source: UN(1976).

Population grouping	1950	1975	2000	2030
Region IV				
Cities	19	36	53	65
Towns	22	24	22	20
Villages	59	40	25	15
Region V				
Cities	6	13	23	44
Towns	8	9	11	11
Villages	86	78	66	45
Region VI				
Cities	14	29	45	65
Towns	12	16	17	17
Villages	74	55	38	18

For the projections of useful and final energy demand for different sectoral activities in 2000 and 2030 we shall use the results of a detailed energy demand analysis (Khan and Hölzl 1981) carried out with the help of a model called MEDEE-2 (Lapillonne 1978, Hölzl 1981) in connection with the medium- to long-term global energy study recently completed by the Energy Systems Program Group of IIASA (1981). The various assumptions and projections concerning growth of population, growth and evolution of economy, lifestyle changes, technological improvements, conservation measures, and growth of useful and final energy consumption until 2030, in two different scenarios called Low and High, are described in detail by Chant (1981), Khan and Hölzl (1981), and the Energy Systems Program Group of IIASA (1981) and will not be discussed here. Table 7 summarizes the relevant information on population, gross domestic product, commercial final energy consumption, the share of electricity in this final energy consumption, and noncommercial energy consumption for each of Regions IV, V, and VI for the base year 1975, together with the corresponding projections for 2000 and 2030 in the two scenarios. Additional information about the demands for electricity, useful thermal energy, and liquid fuels (for specific uses), together with their sectoral distributions in 1975, 2000, and 2030, is given in Tables 8, 9, and 10 for Regions IV, V, and VI. The three tables also list those parts of the demands for electricity and useful thermal energy (including coke requirements) that

TABLE 7 Projections of population, GDP (in constant 1975 US dollars), final energy (commercial), and noncommercial energy in the IIASA High and Low scenarios.

Parameter	1975	2000		2030	
		Low	High	Low	High
Region IV					
Population (10^6)	319	575		797	
GDP (10^9 \$)	340	918	1272	2229	3569
Final energy (commercial) (GWyr)	255	733	1004	1656	2640
Share of electricity (%)	10	12	12	16	15
Noncommercial energy (GWyr)	109	109		109	
Region V					
Population (10^6)	1422	2528		3550	
GDP (10^9 \$)	340	924	1207	1995	3488
Final energy (commercial) (GWyr)	253	802	1063	1876	3173
Share of electricity (%)	9	12	13	15	16
Noncommercial energy (GWyr)	344	344		344	
Region VI					
Population (10^6)	133	247		353	
GDP (10^9 \$)	190	643	900	1310	2918
Final energy (commercial) (GWyr)	106	434	578	868	1638
Share of electricity (%)	4	12	12	15	17
Noncommercial energy (GWyr)	10	10		10	
Regions IV + V + VI					
Population (10^6)	1874	3350		4700	
GDP (10^9 \$)	870	2485	3379	5534	9975
Final energy (commercial) (GWyr)	614	1969	2645	4400	7451
Share of electricity (%)	8	12	12	15	16
Noncommercial energy (GWyr)	463	463		463	

TABLE 8 Projections of demands for electricity, useful thermal energy, and liquid fuels and of possible shares of S/D renewables for Region IV. Electricity and liquid fuel demands are expressed as final energy. Useful thermal energy is expressed in terms of equivalent requirements of electricity.

	1975	2000		2030	
		Low	High	Low	High
Demand for electricity (GWyr)	24	85	119	256	402
Shares of sectors (%)					
Households	21	22	22	23	23
Services	8	10	9	13	8
Manufacturing	62	57	60	52	58
Agriculture	1.2	4.0	3.2	4.0	2.9
Others	8	7	6	8	8
Demand to be met by S/D renewables (GWyr)	0	0.9	1.3	12.9	18.6
Demand for useful thermal energy (GWyr)	68	182	247	390	616
Shares of sectors (%)					
Households	30	28	21	25	18
Services	1.2	1.4	1.0	2.2	1.1
Manufacturing[a]	69	71	78	73	81
Demand to be met by S/D renewables (GWyr)	8	52	65	179	269
Shares (GWyr)					
Soft solar	0	2.9	4.1	22	33
Charcoal, biogas	0	39	51	141	220
Noncommercials	8	10	10	16	16
Specific demand for liquid fuels[b] (GWyr)	132	389	533	939	1507
Shares of sectors (%)					
Agriculture	0.6	2.2	1.8	2.7	1.9
Transportation	79	78	76	76	75
Others	20	20	22	21	23

[a]Coke requirements of the steel industry are included on an equivalent calorific basis.
[b]Liquids required as feedstocks for petrochemical industries are included.

can be met by S/D renewables on the basis of the assumptions in Section 4 and those made earlier in this section, and that are consistent with the population distribution projections of Table 6.

Using the data of Tables 6–10 as a basis, and the efficiency improvement projections for different fuels and processes as embodied in the MEDEE-2 analysis of Khan and Hölzl (1981), we present in Tables 11 and 12, respectively, the demands in 2000 and 2030 for electricity, nonelectric commercial final energy, and noncommercial energy in villages, towns, and cities of the developing regions and provide details of the contributions from different S/D renewables (wind/hydropower, charcoal, biogas, soft solar) in the three types of demand center.

Assuming that the share of villages in the regional consumption of noncommercial fuels in 1975 was about 60% for Region IV, 85% for Region V, and 75% for Region VI, we estimate that only about 6% of that year's demand, both for total commercial final energy and for electricity alone, in the developing regions (IV + V + VI) originated from

TABLE 9 Projections of demand for electricity, useful thermal energy, and liquid fuels and of possible shares of S/D renewables for Region V. Electricity and liquid fuel demands are expressed as final energy. Useful thermal energy is expressed in terms of equivalent requirements of electricity.

	1975	2000		2030	
		Low	High	Low	High
Demand for electricity (GWyr)	22	95	133	274	509
Shares of sectors (%)					
Households	7	8	7	10	10
Services	10	11	10	10	9
Manufacturing	75	61	66	57	66
Agriculture	6.4	18	15	19	13
Others	1.8	1.8	1.6	3.4	2.6
Demand to be met by S/D renewables (GWyr)	0	2.1	2.6	31	45
Demand for useful thermal energy (GWyr)	100	249	331	508	883
Shares of sectors (%)					
Households	38	31	24	30	18
Services	0.1	0.2	0.2	0.3	0.3
Manufacturing[a]	62	69	76	70	82
Demand to be met by S/D renewables (GWyr)	26	88	104	239	376
Shares (GWyr)					
Soft solar	0	1.0	1.4	15	30
Charcoal, biogas	0	58	73	183	305
Noncommercials	26	29	29	41	41
Specific demand for liquid fuels[b] (GWyr)	80	309	391	896	1425
Shares of sectors (%)					
Agriculture	3.4	10.7	9.5	11.3	8.7
Transportation	82	70	68	67	63
Others[a]	15	19	23	22	28

[a]Coke requirements of the steel industry are included on an equivalent calorific basis.
[b]Liquids required as feedstocks for petrochemical industries are included.

the requirements* of villages. The share of villages in total final energy, for all three regions taken together, does not change significantly over the next 50 years (Table 13) despite increased urbanization. On the other hand, the share of villages increases by a factor of about 2 if only electricity demand is considered. These results are consequences of the increasing energy intensiveness of agriculture assumed in the MEDEE-2-based energy demand projections and the assumptions of Section 3 concerning rural electrification and use of noncommercial fuels.

Table 14 shows the shares of S/D renewables in the electricity, nonelectric commercial final energy, and total commercial final energy demands of villages, towns, and cities

*The commercial final energy requirements of villages are assumed to consist of the demand of the agricultural sector for irrigation and tractor operations, etc. and the commercial energy requirements of rural households for those needs that are not satisfied by the available supplies of noncommercial fuels. The rural population would also have some share in the transportation energy but this is generally very small and has accordingly been neglected here.

TABLE 10 Projection of demands for electricity, useful thermal energy, and liquid fuels and of possible shares of S/D renewables for Region VI. Electricity and liquid fuel demands are expressed as final energy. Useful thermal energy is expressed in terms of equivalent requirements of electricity.

	1975	2000		2030	
		Low	High	Low	High
Demand for electricity (GWyr)	4.7	53	69	133	270
Shares of sectors (%)					
Households	13	9	10	12	15
Services	8	10	9	16	13
Manufacturing	77	77	77	64	67
Agriculture	2.1	3.6	3.2	5.8	3.7
Others	0.4	0.5	0.5	2.4	2.0
Demand to be met by S/D renewables (GWyr)	0	0.5	0.7	7.8	13.9
Demand for useful thermal energy (GWyr)	18.4	113	142	209	395
Shares of sectors (%)					
Households	41	20	18	23	14
Services	2.3	2.6	2.3	5.2	3.8
Manufacturing[a]	57	77	80	72	82
Demand to be met by S/D renewables (GWyr)	0.7	25	30	90	157
Shares (GWyr)					
Soft solar	0	0.5	0.7	8.4	16.1
Charcoal, biogas	0	23	29	80	139
Noncommercials	0.7	0.8	0.8	1.2	1.2
Specific demand for liquid fuels[b] (GWyr)	69	214	300	466	870
Shares of sectors (%)					
Agriculture	0.6	2.3	1.9	2.6	1.8
Transportation	60	67	66	67	70
Others[b]	39	31	32	30	28

[a]Coke requirements of the steel industry are included on an equivalent calorific basis.
[b]Liquids required as feedstocks for petrochemical industries, as well as gas used in petroleum mining, are included.

in Regions IV, V, and VI, based on the IIASA High scenario energy demand projections. The results for the Low scenario are not very different and have, therefore, been left out. According to Table 14, by 2030 S/D renewables should be able to meet about 35% of the electricity requirements of villages and 15% of those of towns in each region. The commercial renewables will be meeting about 22% of the nonelectric commercial final energy demand of villages, and 17% of that in urban areas (towns, cities) of the three regions taken together. The share of commercial renewables in meeting the energy requirements of the developing regions in 2030 could be, according to the present assessment, as high as 7% of electricity and 17% of nonelectric commercial energy, which amounts to about 15% of the total commercial final energy. In quantitative terms S/D renewables would be required to supply in 2030 about 78 GW(e)yr yr^{-1} of electricity and 1055 GWyr yr^{-1} of nonelectric final energy (charcoal, biogas, soft solar), according to the High scenario. The corresponding figures in the Low scenario would be 52 GW(e)yr yr^{-1} and 657 GWyr yr^{-1} (Table 12).

6 SOME SUPPLY CONSIDERATIONS

The amounts of electricity generated by wind/small-scale hydropower, and of non-electric energy in the forms of charcoal, biogas, and soft solar that will be required in 2000 and 2030 in Regions IV, V, and VI, on the basis of our assumptions in conjunction with the IIASA energy demand projections, have been detailed in Tables 11 and 12. The greatest pressure on sources of S/D renewables, within the time horizon of the present assessment, will be in 2030 in each scenario; moreover, this will be greater in the High than in the Low scenario. We shall therefore discuss the supply of S/D renewables mostly with respect to the High scenario demand for the year 2030.

The per capita demand for electricity in the villages of Regions IV, V, and VI in 2030 is expected to be in the range of 0.06–0.27 kW(e)yr yr^{-1} for the High scenario (Table 15). The corresponding demand in the towns of these regions would be 0.2–0.9 kW(e)yr yr^{-1}. For a typical village of 500 inhabitants and a typical town of 20,000, the power requirements would be 30–135 kW(e)yr yr^{-1} and 4–18 MW(e)yr yr^{-1}, respectively. Thus windmills/small hydropower units (or groups of units) with peak power capacities between just a few kW(e) and a few hundred kW(e) would be needed to meet the requirements of villages, whereas larger systems, with capacities between several hundred kW(e) and a few tens of MW(e), would be necessary to meet even the low-priority requirements of towns. Still these larger systems are considered here as S/D renewables since they may well consist of several separate units that may or may not be connected to each other or to a conventional power plant.

A much larger fraction of human population has settled close to rivers and streams than near the coasts (where wind is strong), so it is assumed that about two-thirds of the power generation by S/D renewables in each region would be based on small-scale hydropower and the remaining one-third would be derived from wind energy. Such an assumption does not call for utilizing more than about one-tenth of the hydropower potential in each of Regions IV and V, but in Region VI it would imply utilizing about 40% of the hydropower potential via decentralized power generation (Table 16). Regions IV, V, and VI used only about 7, 4, and 6% of their respective hydropower potentials in 1975 and that output practically all originated from centralized power generation.

Of the noncommercial fuels used in the developing regions in 1975 about 25 GWyr in Region IV, 115 GWyr in Region V, and 8 GWyr in Region VI are estimated to have been produced from agricultural and animal wastes. The total amounts of such wastes produced in the regions in 1975 are estimated to have been about 83, 300, and 23 GWyr, respectively (Parikh 1978, Revelle 1979). By 2030, higher agricultural production will probably increase these amounts by a factor of 3.5–4.5. (Even no change in agricultural production per capita would need an increase in total agricultural production by 2.5 times.) The requirements of biogas for rural households in 2030 have been estimated (Table 12) as 35–40 GWyr for Region V and 12–14 GWyr for Region VI. This implies that by 2030 some 60–65 GWyr yr^{-1} of agricultural and animal wastes would be used for biogas production in Region V and about 20–25 GWyr yr^{-1} in Region VI, at a biogas conversion efficiency of about 60% (Makhijani and Poole 1975). Thus the production of biogas to the extent envisaged in our assessment would not put any excessive pressure on production of agricultural and animal wastes. Most of these wastes will still remain available in each region for use as noncommercial fuels, for returning to the fields, and for other applications.

TABLE 11 Projections of demands for electricity, nonelectric commercial final energy, and noncommercial energy by villages, towns, and cities in the year 2000, and shares of S/D renewables (GWyr). The energy demands of villages are assumed to comprise requirements of rural households and agriculture. The energy demands of towns and cities are obtained by distributing the urban demand in proportion to population.

Demand sector	Low			High		
	IV	V	VI	IV	V	VI
Villages						
Electricity	6.6	20.8	3.1	8.2	24.0	3.8
Contribution from wind, small-scale hydropower	0.4	1.5	0.2	0.5	1.7	0.2
Nonelectric commercial energy	14.1	76.7	19.3	15.2	82.1	21.7
Contribution from						
Charcoal	–	14.3	4.2	–	14.8	4.6
Biogas	–	14.3	4.2	–	14.8	4.6
Noncommercial energy	105.0	344.0	10.0	109.0	344.0	10.0
Towns						
Electricity	22.9	23.8	13.5	32.2	34.9	17.6
Contribution from wind, small-scale hydropower	0.5	0.6	0.3	0.8	0.9	0.4
Nonelectric commercial energy	183.6	201.7	97.5	252.3	271.1	131.5
Contribution from						
Charcoal	17.7	24.7	7.7	22.9	32.3	9.7
Soft solar	1.0	0.3	0.1	1.2	0.5	0.2
Noncommercial energy	4.0	–	–	–	–	–
Cities						
Electricity	56.0	50.5	36.5	78.9	74.3	47.5
Contribution from wind, small-scale hydropower	–	–	–	–	–	–
Nonelectric commercial energy	449.6	428.7	263.7	617.7	576.1	355.5
Contribution from						
Charcoal	43.3	52.5	20.9	56.1	68.7	26.2
Soft solar	2.5	0.7	0.4	2.9	1.0	0.5
Total						
Electricity	85.5	95.1	53.1	119.3	133.2	68.9
Contribution from wind, small-scale hydropower	0.9	2.1	0.5	1.3	2.6	0.7
Nonelectric commercial energy	647.3	707.1	380.5	885.2	929.3	508.7
Contribution from						
Charcoal	61.0	91.5	32.8	79.0	115.8	40.5
Soft solar	3.6	1.0	0.5	4.1	1.4	0.7
Biogas	–	14.3	4.2	–	14.8	4.6
Noncommercial energy	109.0	344.0	10.0	109.0	344.0	10.0

TABLE 12 Projections of demands for electricity, nonelectric commercial final energy, and noncommercial energy by villages, towns, and cities in the year 2030, and shares of S/D renewables (GWyr). The energy demands of villages are assumed to comprise requirements of rural households and agriculture. The energy demands of towns and cities are obtained by distributing the urban demand in proportion to population.

Demand sector	Low			High		
	IV	V	VI	IV	V	VI
Villages						
Electricity	19	65	11	26	88	17
Contribution from wind, small-scale hydropower	7	25	4	9	33	6
Nonelectric commercial energy	28	149	26	32	176	31
Contribution from						
Charcoal	–	–	–	–	–	–
Biogas	–	35	12	–	40	14
Noncommercial energy	87	344	10	98	344	10
Towns						
Electricity	45	42	26	72	84	53
Contribution from wind, small-scale hydropower	6	6	4	10	12	8
Nonelectric commercial energy	261	291	149	419	498	281
Contribution from						
Charcoal	37	52	23	57	87	40
Soft solar	4	3	2	6	6	4
Noncommercial energy	22	–	–	11	–	–
Cities						
Electricity	192	167	97	305	337	200
Contribution from wind, small-scale hydropower	–	–	–	–	–	–
Nonelectric commercial energy	1111	1163	560	1788	1991	1056
Contribution from						
Charcoal	159	207	85	244	347	149
Soft solar	18	12	7	26	24	13
Total						
Electricity	256	274	134	402	509	270
Contribution from wind, small-scale hydropower	13	31	8	19	45	14
Nonelectric commercial energy	1400	1603	735	2238	2665	1368
Contribution from						
Charcoal	196	259	108	302	433	188
Soft solar	22	15	9	33	30	16
Biogas	–	35	12	–	40	14
Noncommercial energy	109	344	10	109	344	10

TABLE 13 Share (%) of villages in commercial final energy demand.

Demand category	1975	2000		2030	
		Low	High	Low	High
Region IV					
Electricity	4.2	7.7	6.9	7.5	6.3
Nonelectric energy	3.0	2.2	1.7	2.0	1.4
Total final energy	3.1	2.8	2.3	2.8	2.2
Region V					
Electricity	8.9	21.9	18.0	23.9	17.2
Nonelectric energy	7.3	10.8	8.8	9.3	6.6
Total final energy	7.4	12.2	10.0	11.4	8.3
Region VI					
Electricity	4.1	5.8	5.5	8.1	6.3
Nonelectric energy	7.3	5.1	4.3	3.5	2.3
Total final energy	7.2	5.2	4.4	4.2	3.0
Regions IV + V + VI					
Electricity	6.1	13.1	11.2	14.4	11.0
Nonelectric energy	5.5	6.4	5.1	5.4	3.8
Total final energy	5.6	7.1	5.9	6.8	5.0

TABLE 14 Fraction (%) of commercial final energy demand met by the projected use of S/D renewables (High scenario).

Demand sector	2000			2030		
	Electricity	Nonelectric energy	Total final energy	Electricity	Nonelectric energy	Total final energy
Region IV						
Villages	6	0	2.1	35	0	15
Towns	2.3	10	9	14	15	15
Cities	–	10	8	–	15	13
Total	1.0	9	8	5	15	13
Region V						
Villages	7	36	29	37	22	27
Towns	2.5	12	11	14	19	18
Cities	–	12	11	–	19	16
Total	1.9	14	13	9	19	17
Region VI						
Villages	6	42	37	36	45	42
Towns	2.5	8	7	15	15	15
Cities	–	8	7	–	15	13
Total	1.0	9	8	5	16	14
Regions IV + V + VI						
Villages	7	33	27	37	22	27
Towns	2.4	10	9	14	17	16
Cities		10	9	–	17	14
Total	1.4	11	10	7	17	15

TABLE 15 Present and projected per capita consumption of electricity (W(e)yr yr^{-1}) as final energy delivered to consumers.

	1975	2030	
		Low	High
Region IV			
Total population average	77	321	504
Urban population average	123	349	555
Rural population average[a]	8	160	214
Region V			
Total population average	15	77	143
Urban population average	64	107	216
Rural population average[a]	1.7	41	55
Region VI			
Total population average	35	378	766
Urban population average	75	424	875
Rural population average[a]	2.6	170	269

[a]Comprises electricity consumption of rural households and of the agricultural sector; rural electrification is assumed to be 25% for Region IV and 15% for Regions V and VI in 1975, and 100% for all regions in 2030.

The supply of charcoal, the most important component o the S/D renewables, will be quite different. According to the present estimates the quantities of charcoal required in the High scenario will by 2030 amount to 302 GWyr yr^{-1} for Region IV, 433 GWyr yr^{-1} for Region V, and 188 GWyr yr^{-1} for Region VI (Table 12). If the efficiency of converting wood to charcoal is 45% (Earl 1975) and there are 5% losses in transportation of charcoal from production sites to towns and cities, the quantities of dry wood (in terms of the energy content of wood) required for meeting these demands will be 704, 1013, and 440 GWyr yr^{-1} for Regions IV, V, and VI respectively.

The regenerative capacity of natural forests in the developing regions, expressed in terms of the average annual increment of dry wood above ground, is estimated at about 3.5 t ha^{-1}, which corresponds to an annual energy production of about 1.95 kWyr ha^{-1} (Earl 1975). Thus the total regeneration in the natural forests of Regions IV, V, and VI amounts to about 2090, 1880, and 55 GWyr yr^{-1}, respectively. In view of the difficulties of access, transportation, management, and environmental safeguards, it is assumed that no more than about one-third of the natural forests in each of these regions would be harvested for producing energy. If concerted efforts are made it would perhaps be possible to reach such a level of exploitation within the next 50 years. This would then supply sufficient wood for the High scenario charcoal demand of Region IV, but not for those of Regions V and VI. In fact the extremely small forest area of Region VI (Table 3) would not be able to cope with even the estimated Low scenario demand in 2030 (108 GWyr yr^{-1}), even if the region's entire annual increment of wood were used for charcoal production.

Owing to the inadequate supply potential of their natural forests, Regions V and VI would have to resort to energy plantation schemes if they decided to use charcoal to the degree envisaged in this assessment. The available literature (e.g. Earl 1975, NAS 1976, Revelle 1979) appears to indicate that fairly high yields of wood (6–30 t ha^{-1} yr^{-1} or more)

TABLE 16 Resource utilization to achieve the projected S/D renewables commercial energy use in 2030. The values are expressed in terms of primary energy equivalents, using conversion efficiencies of 0.37 for electricity, 1.0 for soft solar, 0.45 for conversion of wood to charcoal, and 0.60 for conversion of agricultural and animal wastes to biogas.

	Maximum production capacity ($GWyr\ yr^{-1}$)	Capacity required ($GWyr\ yr^{-1}$)	
		Low	High
Small-scale hydropower			
IV	583[b]	23	33
V	761[b]	56	81
VI	68[b]	14	25
Windmill-generated electricity			
IV	N.A.	12	17
V	N.A.	28	41
VI	N.A.	7	13
Soft solar			
IV	N.A.	22	33
V	N.A.	15	30
VI	N.A.	9	16
Wood from forests			
IV	2090	458	704
V	1880	604	673
VI	55	18	18
Wood from plantations			
IV	N.A.	0	0
V	N.A.	0	340
VI	N.A.	234	421
Agricultural and animal wastes[a]			
IV	291–374	0	0
V	1054–1355	58	67
VI	98–126	20	23

[a]The production capacities correspond to 3.5–4.5 times the estimated production in 1975.
[b]These figures refer to total hydropower-generating capacity including centralized hydropower generation.
N.A.: Not available.

may be obtained from energy plantations by raising specific varieties of fast-growing trees on marginal farmland. If the average annual yield of dry wood is 15 $t\ ha^{-1}\ yr^{-1}$ (i.e. yielding about 8.4 $kWyr\ yr^{-1}$ in the form of wood or 3.8 $kWyr\ yr^{-1}$ as charcoal) energy plantations will be required to cover about 40×10^6 ha in Region V (High scenario only) and 28–50 $\times\ 10^6$ ha in Region VI. These figures should be compared with the present arable land areas in Regions V and VI, which amount to about 450×10^6 ha and 45×10^6 ha, respectively (Table 3). These are large operations, particularly for Region VI, but they may still be feasible if proper governmental support is provided to convert some of the permanent pastures and other land into energy farms.

Although our assumptions about the use of solar devices for space and water heating in buildings and hot-water/steam production for use in industry are optimistic, the share of soft solar energy in meeting the final energy demand in developing regions would not exceed much above 1% by 2030 (Table 12). If only manufacturing requirements of final energy are taken into consideration the share would be about 1.7% in each region. A rather high contribution of soft solar, at a level of about 5%, is also expected in the final energy demand of the household/service sector in Region IV where central heating is more common than in the other regions.

Table 16 reports both the estimated maximum production capacity in each of Regions IV, V, and VI and the capacity required in 2030 for meeting that part of the final energy demand in the two IIASA scenarios that is considered appropriate for S/D renewables in the present assessment.

7 CONCLUSION

The assessment in this report has shown that the soft/decentralized technologies based on renewable energy sources, if fully supported by national policy measures, may meet in 2030 about 7% of the electricity demand and about 17% of the nonelectric commercial final energy requirements of the developing regions. Our assumptions for identifying the potential markets for soft/decentralized renewables and for estimating the extent of their penetration into the appropriate potential markets within feasible limits (in our judgment) have been clearly stated. We believe that efforts to introduce these renewables at a higher scale would result in undue hardships to the users, and may also adversely affect economic development.

Of the electricity demand in 2030 in the developing regions about 13% would arise from the requirements of the rural population (including irrigation requirements) and about 17% from those of small towns. It is estimated that in 2030 about 37% of the electricity requirements of rural areas and some 14% in small towns may be supplied by decentralized, small hydropower units and windmills.

About 60% of the nonelectric final energy demand in the developing regions in 2030 would be for transportation, construction, mining, agriculture (mainly tractor fuel), and feedstock production activities (Khan and Hölzl 1981) and would be essentially all met by liquid fuels. The remaining 40% would be thermal requirements, which would define the main role of S/D renewables in the nonelectric sector. The use of commercial S/D renewables has been envisaged in 2030 to meet about 52% of the thermal requirements of the household/service sector and 36% of those attributed to manufacturing activities. In addition, the use of noncommercial fuels would meet about 18% of the household/service sector requirements of useful thermal energy in 2030.

The shares of biogas, soft solar, and charcoal in meeting the total nonelectric final energy demand of the developing regions in 2030 have been assessed as about 0.9, 1.3, and 14.7%, respectively, in the High scenario. (The shares are almost the same as in the Low scenario.) Thus the most important contribution would come from charcoal. The quantities of wood required in 2030 to produce the necessary amounts of charcoal would be in the range of 2.4–3.9 $\times 10^9$ t for the two IIASA scenarios. These quantities should be seen against the total annual increment of wood in the forests of the regions, which is estimated as about 7.2 $\times 10^9$ t. The situation is even more complicated if regional demands for charcoal and the regional resources of natural forests are considered separately. It turns out that Region VI would need to undertake intensive energy plantation even before the turn of the century, while Region V would be required to do the same later and only in the High scenario. Region IV, on the other hand, has sufficient resources of forests to meet its demand up to 2030 by utilizing not more than about one-third of the annual regenerative capacities of its forests, this being a practical upper limit, in our view, imposed by various constraints. If plantation activities are pursued in Regions V and VI, the land area under plantations in 2030 in the High scenario would be about 10% of the present arable land in Region V and roughly the same as the present arable area in Region VI. Region V, with very limited resources of fossil fuels, would probably have no other choice although the oil-rich Region VI may still consider it unnecessary to follow such a course.

The shares of biogas and soft solar in the total nonelectric final energy demand are rather low despite the incorporation into the assessment of some generous assumptions about their use. This is mainly a result of the limited sizes of their potential markets. Biogas is suitable for use only in rural areas, where a large fraction of the thermal energy requirements would still be met by noncommercial fuels even if the use of such fuels were assumed not to exceed the regional consumption levels of 1975. Soft solar is suitable only for water heating, space heating in detached centrally heated dwellings or low-rise buildings, and steam and hot-water production for manufacturing industries. The generally warm climates of the developing regions make their water- and space-heating requirements low compared with those in the developed regions, which mostly have cooler climates. The demand for hot water and steam by manufacturing industries accounts for only about 40% of their useful heat requirements. A considerable fraction of these industries are generally in or near major cities where scarcity of land precludes large solar installations for hot-water and steam generation.

In our opinion, this assessment of the possible use of soft/decentralized renewables is based on quite optimistic, although still not unrealistic, assumptions. It would call for a well organized, large, and persistent effort on the part of the developing regions if the use of renewables to the extent envisaged were to become a reality within, say, the next 50 years. The resource conditions, with respect to both conventional fuels and renewables, are not the same in all regions. There will even be large variations within each region, if individual countries are taken into consideration. It may well be that countries with abundant resources of oil, gas, or coal or with large potentials of centralized hydropower generation consider it unnecessary to change to soft/decentralized renewables to any significant extent in the next few decades. The unavailability of investment funds from individuals and small groups or unfavorable loan policies of governments may also retard the introduction of S/D renewables in areas where the resource conditions are most favorable to their use. These considerations only tend to lower the share of S/D renewables in meeting the future energy demands. Our present estimates should, therefore, be taken as an upper limit under generally favorable conditions.

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APPENDIX THE THREE MARKET-ECONOMY DEVELOPING REGIONS OF IIASA'S ENERGY SYSTEMS PROGRAM

Region IV: Latin America (LA)

Developing economies with some energy resources and significant population growth.

Argentina	El Salvador	Nicaragua
Bahamas	Guadeloupe	Panama
Belize	Guatemala	Paraguay
Bolivia	Guyana	Peru
Brazil	Haiti	Puerto Rico
Chile	Honduras	Surinam
Colombia	Jamaica	Trinidad and Tobago
Costa Rica	Martinique	Uruguay
Cuba	Mexico	Venezuela
Dominican Republic	Netherlands Antilles	Other Caribbean nations
Ecuador		

Region V: Africa (except Northern Africa and South Africa) and South and Southeast Asia (Af/SEA)
Slowly developing economies with some energy resources and significant population growth.

Africa		
Angola	Kenya	Rwanda
Benin	Lesotho	Senegal
Botswana	Liberia	Sierra Leone
Burundi	Madagascar	Somalia
Cameroun	Malawi	Sudan
Cape Verde	Mali	Swaziland
Central African Republic	Malta	Tanzania
Chad	Mauritania	Togo
Congo	Mauritius	Tunisia
Ethiopia	Morocco	Uganda
Gabon	Mozambique	Upper Volta
Gambia	Namibia	Western Sahara
Ghana	Niger	Zaire
Guinea	Nigeria	Zambia
Guinea-Bissau	Réunion	Zimbabwe
Ivory Coast		
Asia		
Afghanistan	Indonesia	Philippines
Bangladesh	Korea, South	Singapore
Brunei	Macao	Sri Lanka
Burma	Malaysia	Taiwan
Comoros	Nepal	Thailand
Hong Kong	Pakistan	Timor
India	Papua New Guinea	West South Asia, not elsewhere specified

Region VI: Middle East and Northern Africa (ME/NAf)
Developing economies with large energy resources.

Members of the Organization of Arab Petroleum Exporting Countries		*Others*
Algeria	Libya	Iran
Bahrain	Qatar	Jordan
Egypt	Saudi Arabia	Lebanon
Iraq	Syria	Oman
Kuwait	United Arab Emirates	Yemen
		Yemen, South

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Arshad M. Khan gained his Ph.D. in physics at the University of Birmingham, UK in 1964. In 1968 he joined the Pakistan Institute of Nuclear Science and Technology and did experimental work on the nuclear physics of neutron capture reactions. At the same time, Dr. Khan was closely associated with the science and technology planning activities in Pakistan. He joined IIASA's Energy Systems Program in 1978 to study the long-term energy requirements of developing countries, and the options and alternative strategies that could be applied to their particular circumstances. He is now Head of the Applied Systems Analysis Group at the Pakistan Atomic Energy Commission.

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