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Solar Energy and Agriculture

Énergie solaire et agriculture

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SOLAR ENERGY AND AGRICULTURE
ENERGIE SOLAIRE ET AGRICULTURE

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1. PRESENT ENERGY CONSUMPTION IN AGRICULTURE

1.1 Energy use in agriculture

Agriculture uses energy, in both direct and indirect forms, for various purposes (traction, hoeing, pumping, harvesting, drying, storage, transport, processing etc.). Direct forms of energy used in agricultural production are fossil fuels, electricity, solar radiation, animal and human labour. Indirect energy forms include chiefly fertilizers and pesticides. With varying degrees of efficiency, agricultural activities also produce energy, i.e. primary production of biomass through photosynthesis. Biomass fuels such as wood, agricultural residues and purposely grown energy crops are widely utilized. Another path, though energetically inefficient, is conversion of plant material into animal products. Livestock production, particularly ruminant production, however, is not inherently wasteful because it provides also food, mechanical energy and fertilizer from otherwise often wasted non-edible material (crop by-products and residues). It is therefore appropriate to refer to agriculture as an energy conversion process.

Some forms of energy produced in agriculture (plant residues, animal traction and manure), again, are partly used as an input into further agricultural processes, e.g. for land preparation and as fertilizer. Depending on the point of view, i.e. accounting for or disregarding the solar input as the primary source of all energy, agriculture can be considered a net producer or a user of energy. However, depending on the degree of integration, farming or production systems can be characterized by their relative dependency on external (energy) inputs. The use of external inputs is increasingly intensive due to the narrowing ratio of available arable land per caput and the need to produce ever more food from the limited land resources: external inputs to agriculture have an important land substituting role. Rural energy demand, however, entails besides agricultural needs also household activities, e.g. cooking and heating/cooling, accounting for 40 to 70 % of rural energy consumption (1). It also includes energy for the processing of agricultural products.

Agriculture's share of a country's total energy consumption is normally in the range of 5%, whilst the entire system (from land preparation to processing) may require 15% or more of developing nations' energy needs. Agro-processing (boiling, peeling, drying, sterilizing, canning etc.), however, is normally done in urban areas and the energy used is accounted for in the industrial energy budget. The rural sector (including non-agricultural activities such as rural industries) of developing countries accounts for almost 40% of the total energy consumption. This comparatively high proportion is reflecting the relatively low development of the industrial sector and other productive activities. The particular challenge is to ensure that agricultural energy needs are fulfilled in a timely fashion since there are narrow time frames for the optimization of farm operations such as irrigation and fertilization (2).

It is the objective of this paper to discuss the opportunities offered by <u>solar</u>[1] energy in agriculture and rural development and to identify the main areas for national and international action to mobilize <u>solar</u> energy's contribution.

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[1] The term <u>solar</u> refers to the renewable energy sources (solar, wind and biomass) considered in this paper.

1.2 Trends in energy use in agriculture

There is, however, the question of how agriculture uses different sources of energy and how its needs are met from available energy resources. This leads to the challenge of how different energy options are exploited for given problems of rural energy supply. Supply problems are rooted in the lack of assessment as well as wastage of local resources, geographic isolation of rural communities and difficulties in energy distribution, and the lack of energy infrastructure. Available information on energy use mostly refers to the so-called commercial or rather non-renewable energy. The use of conventional energy includes fertilizer, manufacture and operation of farm machinery, pesticides, and irrigation. There are few reliable estimates of the overall energy use which includes the use of biomass fuels (fuelwood, charcoal and others) for cooking and other household needs and accounts for the major share of rural energy consumption in developing countries. Other uses of energy which are usually not quantified include solar energy (for traditional solar drying), and human energy (e.g. handpumps). Furthermore, the energy consumed by the fertilizer industry is usually accounted for in the energy budget of the industrial sector and transport and draught animal power are not included in the agricultural energy budget. Conventional energy balances alone therefore greatly underestimate the actual total energy consumption of agriculture and of the rural sector as a whole (2). Even more important, projections of future energy demand rarely consider the requirements for lifting agricultural productivity and for enhancing the level of life of rural populations.

In the 1970s, when oil prices quadrupled in the beginning and doubled again at the end of the decade, there was an increased interest in the economy of conventional or non-renewable energy in agriculture, particularly so in the developing countries which were facing severe problems with their balance of payments. The large increases in crop yields had been brought about mainly through the use of energy-intensive inputs vis-a-vis the need to meet a rapidly rising food demand of bulging populations. This development essentially entailed the rapid increase in the application of conventional energy in agriculture. This trend continued during the 1970s and early 1980s, probably due to high marginal returns from the use of conventional energy in agriculture in developing countries and despite increased real energy prices, a world recession, lower export prices and growing problems of foreign debts.

Agriculture (excluding household activities, transport and processing) worldwide uses only a small, but nevertheless increasing part of the non-renewable energy consumption (5% in 1982 vs. 4.2% in 1972). There are notable differences in agricultural productivity and energy use and availability among regions and countries. During 1972-1982, the financing of an increasing demand for conventional energy was a major problem for most oil-importing countries. Agriculture's share of total conventional energy used in developing countries was higher than in developed countries (4.9% vs. 4.1% in 1972 and 6.5% vs. 4.9% in 1982). Of the world total energy use in agriculture, the developing countries' proportion rose to nearly 27% in 1982 from only 17% in 1972. During that decade, agriculture's share of energy fell only in the Near East; it rose marginally in Africa, and soared in Asian Centrally Planned Economies (ACPE) and, most markedly, in the Far East (from 6.5% to 14.1% of total energy used).

Worldwide, **manufacture and operation of farm machinery** accounted for the largest, though declining share of conventional energy used in agriculture (58% in 1972 and 52% in 1982), with Oceania having the highest levels (74% in 1972 vs. 72% in 1982) and the Far East and the ACPE the lowest (17% in 1972 vs. 16% in 1982). Next came **chemical fertilizers** with 39% of the world total in 1972 and 44% in 1982. It is notable, however, that in developing regions alone fertilizer came first with 64% of their total energy used in agriculture for this purpose in 1972 and 69% in 1982. Manufacture and operation of irrigation equipment, as well as pesticides, on the other hand, accounted for only about 2% in both 1972 and 1982, with the highest proportions in the Near and Far East.

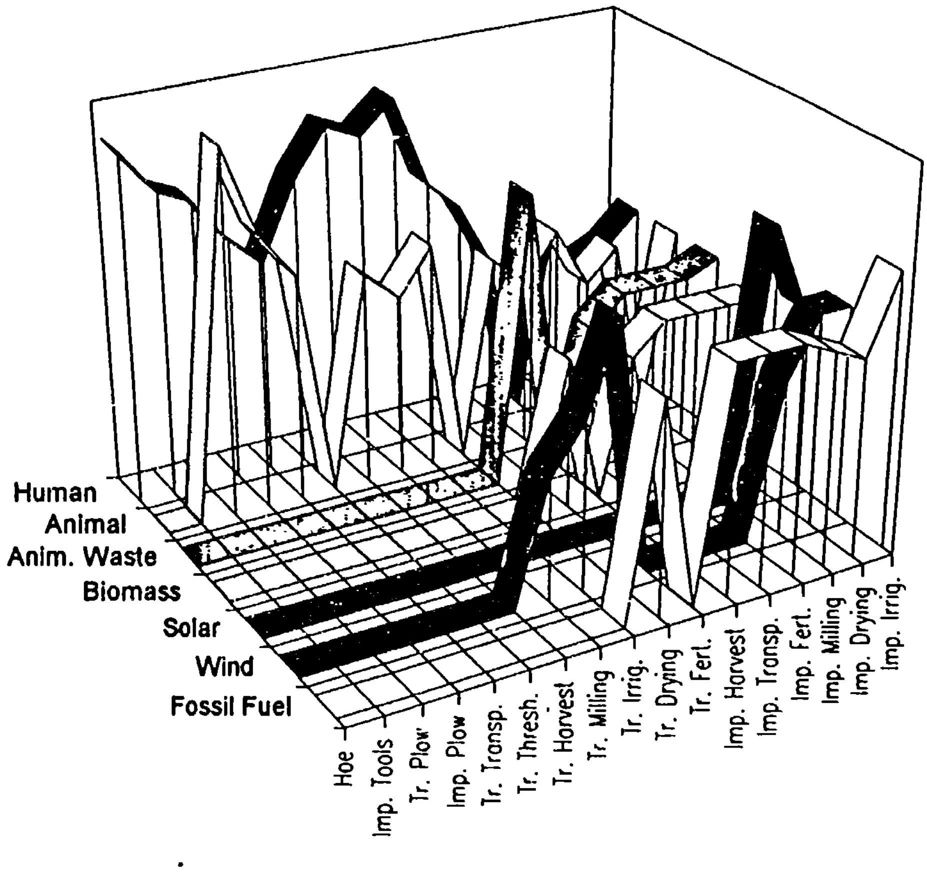
When comparing the efficiency of energy used in agriculture, there are marked differences between developed and developing regions, which is also true for levels of output. For example, North American agriculture used per agricultural worker in 1982 1000 times more energy than African agriculture, while output was less than 100 times that in Africa. Per unit area, though, these regional differences diminish considerably due to varying levels of intensity of cultivation. However, the incremental gains in output from large amounts of energy used in developing countries are considerably below those of developed countries: a 130% rise in conventional energy in developing countries was associated with a 38% rise in output, whereas this ratio in developed countries was 25% energy inputs vs. a 16% rise in output (3). This situation can be illustrated by an example from the Philippines: the introduction of improved technology for irrigated rice production increased energy requirements 37-fold, involving the use of inorganic fertilizers, pesticides, farm machinery and a diesel pump for irrigation. Reported energy inputs were 6.39 GJ/ha compared to 0.17 GJ/ha for traditional/transitional practices. Rice yields were only about doubled with improved cultivation (4). The low response to incremental energy lends support to the concerns about the costs and viability of energy-intensive Green Revolution development models applied to low-income countries, poor in domestic (conventional) energy resources.

A graphic representation of the changes in energy requirements that can occur with more complex agricultural practices is shown in Figure 1. Although not quantitative, this demonstrates the increasing importance of both renewable and oil-based fuels and the diminishing dependence on human and animal energy. The illustration also shows the activities that consume the most energy. In many developing countries, however, the level of development has not yet reached the stage where any great utilization of agricultural machinery can be observed. Improved farm machinery, including transport and irrigation, and fertilizer account for the largest share, as already pointed out above.

The shift to more intensive agriculture will invariably imply a move from the upper left to the lower right side in our graphic illustration, showing also that there are opportunities for renewable energy sources in the context of agricultural intensification. Biomass, solar and wind energy technologies can substantially contribute in various areas of agricultural production, e.g.

improved practices in fertilization, irrigation, harvesting, drying, milling, and transport.

Fig. 1 Traditional and Improved Technologies vs. Rural Energy Uses



2. FUTURE ENERGY NEEDS AND SUSTAINABLE AGRICULTURE

2.1 Sustainable intensification of agriculture

Sustainable agriculture and rural development (SARD) has been defined by the FAO Council in 1988 as "*...the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.* It is understood that the definition of sustainability varies between countries or rather agro-ecologies. A common denominator, however, is not to compromise increased productivity as well as keeping in mind the need for intra- and intergenerational social equity.

In a historical perspective, important signposts in the formulation and implementation of sustainable development strategies were the 1972 UN Conference on the Environment and the publication in 1989 of the report of the UN Commission on the Environment and Development (the Brundtland Commission). The FAO/Netherlands Conference on Agriculture and the Environment in 1991 discussed and identified problems, strategies and actions required for the attainment of SARD. The Den Bosch Declaration adopted at that Conference subsequently found its way into the UN Conference on Environment and Development (UNCED) in 1992 in Rio and the resulting Agenda 21 which is now a priority agenda for most UN agencies (1).

In the light of the arguments under 1.2, sustainable intensification and protection of the resource base of agriculture emerges as a new paradigm. Under the "industrial" model, increased levels of output are usually associated with decreased energy efficiency: incremental gains are achieved at high costs to the resource base, i.e. through heavy external input use of irrigation, fertilizer and pesticides. Worldwide, the annual growth rate of fertilizer of 2.7% between 1979 and 1989 (10.3% between 1961 and 1985 in developing countries alone) is associated with considerably lower growth rates of the three major staple crops, i.e. rice (2.5%), wheat (2.2%) and maize (1.1%), with the Asia-Pacific Region accounting for the bulk of fertilizer use (2, 3). Cereals, moreover, receive currently more than half of all fertilizer used, with rice and wheat being the biggest drain. Nevertheless, the Green Revolution technologies seem to have reached yield plateaus: increasingly more inputs are needed to maintain current yield levels. There is, however, the undeniable task to feed an estimated eight billion people by the year 2025 and low-input approaches alone will, in all likelihood, not be able to live up to expectations: locally available resources will have to be exploited more efficiently to play a more prominent role in sustainable intensive land use systems.

2.1.1 Fertilizer

The move of the agricultural sector from subsistence to commercial production will be accompanied by an increase in the use of purchased or off-farm inputs. There is no viable alternative to this general trend. Investments are required, though, to establish or expand local production of inputs to limit the use of scarce foreign exchange earnings to import most input needs. In drylands with dominant rainfed agriculture, optimized water use may be the primary factor in increasing yields and economizing on input use. To a lesser degree, herbicide and fertilizer use contribute to this objective. The synergistic effect on agricultural productivity of increased fertilizer use, however, is more pronounced in irrigated areas. The **judicious** deployment of inputs can and has to reduce the pressure on marginal lands and the competition for land use between crop production, forestry and livestock production.

Developing countries have considerably increased their share of global fertilizer use, with particularly high growth rates in Asia. This growth, however, was insufficient in some countries, particularly in Africa, to compensate for nutrient removal by crops with resulting land degradation and declining yields. Statistics on fertilizer consumption, though, do not reflect the use of organic fertilizer (manure etc.). The lack of alternative energy sources (including fuelwood) in many rural areas causes manure to be used as fuel for heating and cooking, thus depriving the cropping system of fertilizer and organic material, weakening the soil structure and decreasing yields.

Fertilizer growth rate projections, based on moderate world economic development, for 93 developing countries are in the range of 4.7% p.a. in 1982/84 - 2000 (see Tables 1 and 2). This is a decline compared to the recent decades, reflecting the higher levels already achieved but also the unfavourable overall economic conditions limiting the possibilities to import fertilizer and provide subsidies (3).

2.1.2 Mechanization

This section, as the one above, discusses only inputs into crop production because the necessary data for the livestock sector are almost entirely lacking.

TABLE 1: **Fertilizer Allocation and Power Input (% contribution) in 1982/84 and 2000**

	Fertilizer allocation to:							Contribution to total power input:		
	Wheat and rice	Coarse grains	Sugar cane	Soybean	Fruits, veget. & pulses	Cotton	Fodder crops	Labour	Tractors	Animals
93 Developing Countries										
1982/84	42.3	11.6	10.6	3.9	11.6	2.9	4.3	71	6	23
2000	42.0	15.5	8.2	5.1	10.2	2.2	4.3	73	7	20
Sub-Saharan Africa										
1982/84	9.8	24.3	12.9	1.3	8.3	7.4	0.5	89	1	19
2000	13.2	37.3	9.6	0.8	8.0	4.5	0.4	90	2	8
Near East/ North Africa										
1982/84	37.7	14.7	1.4	0.6	18.8	6.3	7.9	69	14	17
2000	38.4	22.7	1.1	0.8	16.0	3.6	6.8	74	15	11
Asia (excl. China)										
1982/84	58.9	7.0	7.1	0.3	8.8	1.6	4.0	68	4	28
2000	59.9	6.1	6.3	0.5	7.9	1.5	4.6	71	4	25
Latin America										
1982/84	14.9	17.3	24.3	14.4	12.7	2.6	2.9	59	22	19
2000	14.3	24.8	17.5	18.7	10.7	1.8	2.5	58	28	14

Source: FAO 1987. Agriculture: Toward 2000.

TABLE 2: **Fertilizer and Power Use in 1982/84 and 2000**

	Fertilizer use: million tons	Fertilizer use: kg/ha	Fertilizer use: Growth rate (% p.a.) 1982/84-2000	Power use: Labour (million)	Growth rate (% p.a.) 1982/84-2000	Tractors (thousand)	Growth rate (% p.a.) 1982/84-2000	Animals (million)	Growth rate (% p.a.) 1982/84-2000
93 Developing countries									
1982/84	25.8	43	4.7	535	1.3	3292	4.1	168	0.6
2000	56.0	78		563		6484		185	
Sub-Saharan Africa									
1982/84	1.0	9	6.4	124	1.8	127	3.6	14	1.0
2000	2.8	20		168		230		17	
Near East/North Africa									
1982/84	4.6	72	5.4	33	0.6	879	2.4	8	-0.9
2000	11.1	156		37		1322		7	
Asia (excl. China)									
1982/84	13.8	46	4.3	338	1.2	946	5.2	129	0.7
2000	28.2	81		416		2246		145	
Latin America									
1982/84	6.5	53	4.6	40	0.3	1340	4.2	17	-0.2
2000	13.9	90		42		2686		16	

SOURCE: FAO 1987. Agriculture: Toward 2000.

Labour is by far the major source of power input into crop production, followed by draught animals. Tractors are relatively important only in the Near East, North Africa and Latin American regions (see Tables 1 and 2). The shares of labour and machinery vary among countries with the level of economic development as measured by per caput incomes and with the relative abundance or scarcity of labour in relation to cultivated land (ha per caput). The higher the per caput incomes and the more land cultivated per person the higher the share supplied by machinery. This is largely because the agricultural labour force grows less rapidly in higher income countries and relative costs change in favour of machinery. This process was often reinforced through subsidies. In the future, the latter factor may become less important given the increasing scarcity of foreign exchange in many developing countries and the need to promote agricultural employment in the face of slow overall economic growth. In many countries, the ongoing institutional and economic restructuring and the stress on privatization will also have an impact on investment in energization.

The total power requirements are estimated to increase by some 30% between 1982/84 and 2000 of which harvested area expansion would account for some two thirds and higher yields for most of the balance. Crop mix effects would be very small since overall cropping patterns would not change in favour of the crops which require comparatively more inputs of this type per hectare. Regional differences in the sources of output growth (yields, land) result, subsequently, in differences in the growth of power requirements for crop production growth, e.g. each one per cent increase would require power inputs to increase comparatively more in those regions which depend more on land expansion (sub-Saharan Africa, Latin America) than in those with higher yield contributions to output growth (Near East/North Africa, Asia).

The tractor park growth rate in developing countries is expected to be slower in the future as compared to the past. The regions which accounted for much of the increase in the past are already well advanced in tractorization (Near East/North Africa, Latin America). The agricultural labour force, on the other hand, would continue to grow rather rapidly in Asia and also sub-Saharan Africa, the regions with the lowest incomes and the smallest density of machines in relation to land. Here, conditions for shifting relative prices in favour of mechanization are not likely to occur until 2000. Moreover, in some tropical countries, the agro-ecological conditions, e.g. in the humid tropics, do not lend themselves to mechanized cultivation (3).

2.2 Opportunities for finite and renewable energy sources: energy efficiency and food production

The basic hypothesis of this paper is not to demonstrate the need to develop alternative sources of energy due to the finite availability of conventional energy. There is widespread consensus that the planet's reserves of fossil fuels will not be exhausted in the very near future. For the decades to come, fossil fuels will continue to play a major role in energy consumption. Given the increasing energy requirements in developing countries, the well-known problems of energy supply in rural areas (accessibility and timely delivery) due to a certain urban bias, and environmental concerns about the use of fossil fuels, the point to be made is rather that there are opportunities for renewable sources of energy that promise to contribute significantly to the goal of sustainable rural development. This can best be illustrated by referring to the low output/input ratios of conventional energy sources in agriculture (see 1.2) and by examining the effects of high input use (fertilizer, pesticides and water) on the resource base and certain sectors of the population versus sustainability-enhancing technologies. This approach relates to the concept of externalities (e.g. the value of environmental goods such as air and water difficult to be captured by market prices) and that of intergenerational equity.

There have been several attempts to conceptualize the problem of what are appropriate technologies for agriculture in the light of sustainability considerations. Opportunities for technologies have to be identified within a multi-tiered framework: macro- and socio-economic parameters, agro-ecological conditions, resource endowments, production systems, infrastructure, objectives and quantifiable indicators for sustainability (4). Energy technologies for agriculture have been identified in a similar manner and the sustainability implications applied (resource conservation, environmental compatibility, technical appropriateness, economical viability and social acceptability) have led to the emphasis on renewable energy sources. However, when translating a general concept into an operational strategy, problems are encountered that relate mainly to the location-specific nature of any technological intervention.

Low external input solutions are attractive in the context of replacing high amounts of fossil energy that is needed to produce and operate the modern high-input agricultural systems. Both approaches have advantages and disadvantages. High-input systems imply a lower labour demand, free farmers from drudgery and therefore free labour for non-agricultural activities. Low external input systems reduce both the costs for production inputs and the undesirable fertilizer and pesticide residue problems. High labour requirements, lack of integration of farming systems, small farm size, low soil fertility and rainfall, however, are all factors that make the use of external inputs unavoidable in order to produce enough food.

Crop yields and food supplies are directly linked to energy which is needed in the right form and at the right time. When comparing the energy balances of low- and high-input systems by assigning energy values and defining system boundaries, it often becomes apparent that the latter category is less efficient (see also 1.2). Yet, productivity considerations must not be overlooked in the face of rapidly growing populations: high energy use is directly related to the level of production per unit of land. It can be argued, though, that there are indeed integrated systems with a productivity comparable to that of high-input systems. These systems are most prevalent in South-East Asia and China. Such integration, however, has yet to take place in many areas and to gain social acceptance may require ten or more years (5).

Caution has to be applied, however, when interpreting energy analyses comparing "intensive" and "extensive" systems. An example for this is given in Table 3, presenting the energy use in rice production for various countries. Whilst in modern intensive systems most of the energy inputs will be fossil fuels directed to fertilization, irrigation, mechanisation and processing, in the poorest rural areas of developing countries they will be mainly human and animal energy inputs for land preparation, planting and harvesting. Traditional energy analyses readily conclude that the enhanced use of modern and intensive energy sources will lead to higher productivity. As can be seen from the data, if conventional energy (fossil fuels and electricity) alone is considered, productivity would be highest in countries like India and China. Once all farm operations relying on human and animal energy are included, and food losses due to the lack of conservation and processing are added, the balance turns drastically in favour of countries such as the USA or Japan (6).

TABLE 3: **Energy Use per ha in Rice Production in Selected Countries**

	India	China	Japan	USA
kW/ha Installed (machines and draft animal equivalent)	0.52	0.52	1.1	1.1
GJ/ha Farm operations	21.1	21.1	10.6	7.4
GJ/ha Irrigation and N fertilizers	6.9	12.7	26.4	26.4
Total energy	28.0	33.8	36.9	33.8
Rice yield (t/ha)	1.4	3.0	5.6	5.1
Energy intensity (GJ/ton)	22.1	12.4	7.2	7.3

SOURCE: FLUCK, R.C. 1992. Energy in farm production, Elsevier.

In marginal areas with low population density, difficult transport and certainly for low-price and subsistence crops, however, conventional energy inputs cannot be used economically. Under such conditions, locally available energy sources, human energy and bio-energy have to be used efficiently. However, a drop of subsidies on fertilizer could force many high-input farmers to adopt a low-input strategy (5).

It emerges thus that neither low- nor high-input systems alone offer solutions to the problem of sustainable rural energy supply: emphasis should be put on the promotion of an appropriate energy mix from both fossil and solar sources in accordance with the local natural resource endowment and economic factors. To this end, comprehensive plans are needed for the integrated development and use of appropriate energy sources in rural areas, taking into account long-term economic policies (7).

3. RENEWABLE ENERGY IN AGRICULTURE: PRESENT STAGE OF DEVELOPMENT AND ASSESSMENT OF POTENTIAL

Agriculture, as already pointed out above (see 1.1), has a double role of energy consumer and producer. This latter asset is still to be exploited. Besides using energy from both non-renewable (fossil fuels) and renewable (solar, wind and biomass) sources, agriculture has the potential at the same time of providing renewable energy sources in the form of biomass. Agricultural residues are already playing a major energy role in the sugar, rice and coffee agroindustries. This document does not discuss in detail the technologies for the utilization of renewable energy sources. The reader is referred to the extensive literature that exists on the subject. This Chapter analyzes the contribution and potential of renewable energy sources to alleviate the widespread rural energy crisis in many developing countries and, in particular, assesses the role these sources can play in enhancing agricultural productivity and in lifting the quality of life of rural populations.

3.1 Solar Energy

The solar radiation reaching the earth's surface each year is about 20 000 times the current world energy use. This, again, is only the smallest part of the total energy radiated by the sun.

About 30% of the radiation reaching earth's atmosphere is reflected back into space, further 47% is absorbed as heat by the atmosphere, land and water. About 30% of the solar radiation delivered to the ground is reradiated into the atmosphere and evaporation and precipitation use 23% of the atmospheric solar radiation. Only about 1% of the energy reaching the outer atmosphere is used to produce wind (see 3.2) and ocean currents. Less than 0.03% of the solar energy is used for photosynthesis or biomass production (see 3.3).

Devices to collect and convert solar energy directly into electricity or heat include flat plate and focusing collectors, solar ponds and photovoltaic cells. Current agricultural applications of solar energy include water desalination, lifting and pumping, crop drying, i.e. grain and forage drying, solar cookers, space and water heating, and greenhouses.

In terms of support energy, solar energy has had little impact on agriculture. Problems associated with the use of solar energy are all rooted in the intermittent and distributed nature of solar radiation. This makes it necessary to create expensive collection and storage utilities, besides extensive surface-area requirements, that render solar thermal applications usually uneconomic, particularly with current fossil fuel prices. The costs of converting sunlight into electricity, though, show a steadily decreasing tendency and in some places photovoltaic systems are competitive with other conventional sources of energy. Small-scale water pumps can compete with diesel pumps, particularly for developing country situations. Initial purchase would require foreign exchange but maintenance costs would be lower than for diesel pumps, the fuel is free and most abundant when irrigation needs are greatest (1).

Photovoltaic systems are mature and in some cases, i.e. remote applications such as water pumping, lighting, refrigeration, radio and television reception, have already proved themselves as the most suitable stand-alone source of electricity, e.g. in Senegal, where solar electricity appears to be the only viable alternative in rural areas: conventional diesel generators are usually oversized for the low electricity needs and dispersed demand. Nevertheless, the dissemination of this technology has been slower than anticipated, mainly as a consequence of the persisting low prices of conventional energy supplies that do not take into account any social or environmental costs (2). Research needs for solar energy, consequently, are mainly in the area of increased cost-effectiveness. Financial accessibility, either through credit or lowered costs, can break the barrier to implementation in rural areas on a large scale.

Table 4 shows a simple analysis of solar energy technologies and their potential impact on rural development. Photovoltaics, solar water heating and solar drying appear to hold the greatest potential. The sub-sectors where solar energy technologies have the greatest potential are rural industries and the commercial and services applications, followed by households and agriculture. Post-harvest technology has been included in rural industry (3).

TABLE 4: **Evaluation of the Potential of Solar Energy Applications for Rural Sub-sectors**

Applications:	Sub-sectors:				
	Agriculture	Households	Rural Industry	Commercial & Services	Total Rating
Cooking		1			1
Water heating		2	2	2	6
Space heating		2	1	1	4
Drying	2	1	2		5
Refrigeration			2	1	3
Distillation		1	1	1	3
Sterilization		1		1	2
Electricity					
- photovoltaic	1	2	2	1	6
- solar ponds	1		1		2

1 = limited potential; 2 = strong potential

SOURCE: Adapted from BEST, G. 1990. FAO/DIESA/SAREC Expert Group Meeting.

3.2 Wind Energy

Wind energy is in fact a form of solar energy, accounting for less than 1% of the total solar energy radiation. Due to variations in solar radiation in time and location, temperature differences occur in the atmosphere, leading to variations in atmospheric pressure and resulting in air movement from high to low pressure areas. Wind energy conversion systems, consisting of a wind turbine, tower and related equipment (batteries, pumps etc.) are used for mechanical power (water pumping, irrigation, milling), thermal applications and electricity generation (1).

Electricity generation, however, is a comparatively complicated technology, requiring sophisticated equipment, storage and transmission facilities, besides strong and steady wind. This necessitates usually the participation of the public electricity utility or other technical backstopping.

Mechanical wind energy is a simpler technology and can be maintained and manufactured locally. Especially in Asia many locally manufactured wind pumping designs exist. Conventional electricity displaced wind pumps by the thousands in areas of North Africa, North and South America and China, but there is growing interest in rehabilitation programmes in various countries (3).

During the last decade, wind-power technologies have evolved remarkably, though most of this development is concentrated in the industrialized countries and designed to suit their conditions. Large wind-power systems in Denmark and extensive wind-farm installations in California are examples of electricity generation. Increased energy capture and capacity factors have led to lower electricity generating costs. In developing countries, the need for adaptation of wind technologies is particularly important in the areas of stand-alone rather than grid-connected systems. The demand for water pumping applications is large in developing countries. For drinking water, at least, wind pumps seem to be economically attractive, even with unfavourable wind patterns, as can be illustrated by the Chinese example with a large number of wind generators and pumps in operation (2). It is expected that wind-powered systems will find extensive applications in developing countries. As with solar energy, increased cost-effectiveness is a priority area for research on improved wind-power technologies. The continuous development of new materials that yield lighter, stronger components, advanced airfoils and variable-speed turbines are all recent developments and further efforts in this direction will be reflected in lower production costs for electricity.

3.3 Biomass Energy

Biomass production is the result of carbon fixation by plants through photosynthesis, i.e. the photochemical reduction of carbon dioxide with electrons from water. It combines the energy inputs from solar radiation and cultural energy (fertilizer, fuels), besides soil nutrients and water. Inorganic compounds, water and carbon dioxide are synthesized into carbohydrates (sugar, starch, cellulose, lignin): hence solar energy is stored chemically. Total world annual energy consumption is equivalent to only one-tenth the amount of photosynthetic energy stored annually in biomass, albeit the very low efficiency (0.1 - 0.2%) of photosynthesis which is largely due to the variation of a number of environmental factors such as light intensity, temperature, water availability and carbon dioxide concentration (1).

Biomass, including wood, perennials, crop residues and animal manure, currently provides around 14% of the total energy consumed in the world. In developing countries alone, it provides the bulk of all energy used (30 to 90%), mainly at the household level (cooking, heating). The role of growing biomass as carbon sink is a strong argument for the present efforts to convert biomass into energy, e.g. energy plantations, fast growing trees, and the use of residues to substitute fossil fuels. The environmental and social benefits derived from all these options include new job opportunities in rural areas and reduced greenhouse gas (CO_2) emissions (4).

The most common form of biomass energy is **fuelwood**. About 80% of the wood harvested in developing countries is used for cooking, heating or small-scale rural industries. In 1985, this represented 1408 million cubic meters of wood. It is predicted that within the next ten years about three billion people will be affected by fuelwood shortages, resulting inter alia in substantially increased collection time for fuelwood.

National efforts at reforestation for meeting the energy requirements have not had much success and holistic approaches such as agroforestry and social forestry have been receiving considerable interest to solve not only the problem of fuelwood supply but contribute to sustainable rural development. Traditional agroforestry has been practised for many centuries in various parts of the world. To meet the requirements of food, forage, shelter and fuel, trees can be planted on land that would not support food crops. It has been demonstrated that crop yields can be maintained and even increased through improved agroforestry practices (3). Agroforestry systems assist in diversifying land use and maintaining soil fertility and structure (N-fixing trees). The planting of trees, however, encounters problems of land tenure and reform, particularly as regards the rural poor, which have to be dealt with prior to attempts at large-scale adoption (5). Social forestry, a further concept for integrated reforestation, forms the administrative and extension capabilities to sustain such activities and encourages community participation, using communal nurseries and plantations, improved cookstoves and the development and commercialization of wood products to meet market requirements (6).

3.3.1 **Biomass fuels**

Although fuelwood is the predominant energy source in many of the poorest countries, this is not always the case: in India, the energy from dung and residue combustion totalled over 110 million tons against 133 million tons of fuelwood in 1985. In China, the weight of available dung and agricultural residues is 2.2 times the weight of fuelwood (7).

Biofuels are solid, liquid or gaseous products from a wide range of organic feedstocks, obtained through biological and thermochemical conversion processes. The potential conflict between food and biofuel-energy development through plantations and conversion facilities, however, implies that in many countries energy production has to be based on abandoned and marginal lands and low cost residues (8). In some countries, land availability and national energy policies have led to the establishment of large energy plantations to produce ethanol for transport.

3.3.1.1 **Feedstock options**

Biofuel feedstock options include **agricultural residues**, municipal solid waste, **industrialized energy plantations**, and a mix of the above, complemented with fossil fuels.

Considerable amounts of process **residues** are generated in agro-industries, particularly sugar cane refineries, rice milling plants and forest industries, corresponding to nearly the commercial energy consumption in developing countries worldwide. These residues are routinely burnt inefficiently as a source of fuel for process heat and power demand. Similarly, a large part of field residues is presently burnt either prior to or after harvest. There are advanced conversion systems, with a capacity to generate forty times as much electrical energy from residues than is presently produced, whilst in addition meeting the thermal energy requirements of agro-industries. The economic use of field residues depends largely on their collection and transport costs. Here, too, recently developed mechanical harvesters, briquetting equipment and whole plant harvesting are expected to reduce costs considerably. Further research activities in this direction could bring about the more economic use of the large amount of wasted field residues produced worldwide. Guidelines specific to farming systems and agro-ecologic conditions will have to be established in order to assess residues' potential role as energy sources vis-a-vis other uses such as fodder, fertilizer and construction material. A well established source of biomass energy is animal dung. There is large potential to promote small, medium and large scale anaerobic digesters, using the de-gassed sludge as organic fertilizer. In order to meet off-season fuel needs, given that biomass feedstock is available only during the harvesting season, a mix of feedstock supplies in an integrated resource planning approach can be considered. Options include residues, municipal solid waste, land fill gas, biogas from sewage sludge and animal waste, energy plantations, forest biomass and fossil fuels (8).

Short rotation **industrialized plantations** have been widely tested on a small scale. Reasonable yields can be achieved on marginal or degraded lands, besides offering other advantages, i.e. maintaining soil fertility and preserving biodiversity. Specific polycultural mixtures and matching of species to sites are techniques which have proven to yield higher total wood volumes as compared to monocultures. In developing countries, short rotation plantations include various species of Eucalyptus and nitrogen-fixing plants such as Leucaena and Albizia. Sugar cane is another candidate for energy plantations. Sugar cane has the multiple potential to produce alcohol and electricity. There is a total of 80 countries which have considerable land areas under sugar cane (8). Besides being an energy source, sugar cane can support intensive animal production in the tropics, with associated methane:meat ratios being very low (9). There are also substantial efforts under way to use vegetable oil as fuel in diesel engines. Candidate crops include sunflower, peanut, rapeseed and oil palm. The costs of the vegetable fuel as well as those of the modified engine are expected to be competitive in the future (1, 10).

The future potential of energy plantations has to be seen in the light of new bioengineered crops that may lead to substantial yield increases and cost decreases. Examples include the new varieties of sweet sorghum which have been developed in order to provide both grain for food and stalks for alcohol production from sugar (11). Dual food and energy production, using agroforestry techniques, through the adoption of intercropping practices are a further area with already some positive results and scope for future development. Research into the optimization of energy plantations should incorporate energy input and output studies to monitor net energy flows in the production and use of biomass. Further research needs are in the areas of harvesting and collection of biomass, integrated biomass production and use, and improved management practices (8).

3.3.1.2 Technology options

The technology options to use biomass energetically include **direct combustion, carbonization, anaerobic digestion, fermentation/distillation, advanced gasification, cogeneration** and **pyrolysis**. There are some technical problems associated with biomass conversion systems, i.e. large volumes to be handled, the accumulation of tars and the disposal of effluents and ashes, and in some cases drying as a prerequisite to higher efficiency.

Direct combustion is a well developed technology for thermal and electrical power generation, using a wide variety of furnaces for different non-homogenous fuels. Modern **carbonization** processes produce charcoal with an efficiency of 30% and above.

Anaerobic digesters are widely used in the developing world, particularly in the pioneering countries, India and China. The attractivity of this option stems largely from the combination of energy production and the use of slurry as fertilizer (8). In China, 25 million people use biogas as energy for domestic consumption and over seven million biogas plants were built over the past 10-15 years, though many are presently not fully operational (7).

The conversion of fermentable biomass into liquid fuels has made significant progress during the past years through **fermentation/distillation** technologies. Both in developed and developing countries, ethanol production from sugar cane and corn feedstocks is regarded as a mature technology.

Higher fermentation efficiency can be achieved through centrifugal yeast reclamation and continuous evaporative removal of ethanol (8). In Brazil, since the creation of the National Alcohol Programme in 1975, over 85 billion litres of ethanol fuel, mostly from sugar cane, were produced and over 3.5 million vehicles run on straight ethanol, with 9 million vehicles running on gasoline/ethanol blend. Additionally, technologies have been developed to convert stillage wastes into fertilizer, animal feed, and further energy generation (7). New technologies and processes exist to produce ethanol and methanol from cellulose-based feedstock, using the residual fraction, mainly lignin, for heat and power **cogeneration** through combustion. Estimates for this technology indicate that with advanced distillation systems ethanol will become a competitive fuel. The extraordinary efficiency of cogeneration processes compares very favourably with conventional electricity generation: while the latter produces only 33% of the input as useful energy, cogeneration recovers, besides the electrical energy, also more than 40% of the energy input in the form of heat.

Much support during the last decades went into **gasification** technologies, offering a more controlled and better combustion efficiency, higher reactivity and lower emissions as compared to direct combustion. The high efficiencies of modern gas turbines allow for electricity production costs comparable to or below the costs of fossil-fuel derived electricity (8).

Pyrolysis of biomass to produce solid, gaseous or liquid fuels has gained scientific and technical interest in the last decade due to its high conversion efficiency and its multi-product potential. It is expected that both small and large scale commercial pyrolysis systems will be available in the near future. Direct substitution of diesel with only minor adjustments to engines could offer new opportunities for agricultural mechanization, especially in remote areas where biomass-derived fuels could be produced. Research into more economic and reliable pyrolysis equipment is still required.

In conclusion, biomass-derived energy has a very high potential in both industrialized and developing countries. Its intrinsic linkages with agriculture are obvious, but require further technical, environmental and economic assessment. In some OECD countries, the problem of agricultural surplus production has led to "set-aside" policies which open opportunities to produce renewable energy on land taken out of agricultural production. In developing countries, the possible complementarity or competition of food and energy production needs to be at the centre of decisions in this field, requiring an integration of rural and agricultural policies, in particular regarding land-use and prices.

TABLE 5: **Evaluation of the Potential of Biomass Energy Applications for Rural Sub-sectors**

Applications:	Sub-sectors:					
	Agriculture	Households	Rural Industry	Commercial & Services	Transport	Total Rating
Direct combustion	1	2	2			5
Anaerobic digestion		2	2	1		5
Gasification	2		2			4
Alcohol	1		2		2	5
Pyrolysis	2		2			4

1 = limited potential; 2 = strong potential

SOURCE: Adapted from BEST, G. 1990. FAO/DIESA/SAREC Expert Group Meeting.

Table 5 identifies the potential impact of biomass technologies in the context of rural development programmes. The analysis indicates that direct combustion and biogas hold the most potential, followed by gasification and alcohol production. Rural industry appears to be able to make the most of these technologies, followed by the household sub-sector, agriculture and the commercial and services sub-sector.

The above straightforward analysis, similar to the one applied to solar energy technologies under 3.1 (see Table 4) uses largely subjective criteria and weights to arrive at an assessment of the different technologies' viability for different purposes. It should be mentioned that there are more sophisticated methods of economic and financial analysis available, using several parameters and quantifying most of the aspects that need to be considered when evaluating and comparing the economic viability of possible technical solutions to energy problems (12).

4. ECONOMIC, ENVIRONMENTAL AND SOCIAL ASPECTS OF TECHNOLOGY DISSEMINATION STRATEGIES

Strategies for the dissemination of solar energy technologies have to confront a variety of obstacles underlying all efforts in technology transfer: economic viability and social acceptability are at the core of the problem, often overriding environmental concerns, besides difficulties in financial accessibility of the technology and related services for the intended beneficiaries. This presupposes naturally a participatory approach to assess needs and potentials of any particular target group and area and to suggest technically appropriate solutions to rural energy supply problems. Political commitment, however, is a prerequisite for these efforts.

As pointed out earlier, there are situations where solar energy technologies or a mix of solar and conventional energy are competitive with or superior to conventional energy alone. The factors that determine a rural site's energy needs and shortcomings include existing production systems and their optimization vis-a-vis a given natural resource endowment and agro-ecological conditions, the relative remoteness, and the lack of energy and support services infrastructure. Grid supply is often uneconomical. Energy supply in such situations requires chiefly an assessment of local resources and strategies to minimize their wastage. Appropriate stand-alone solutions as well as energy mixes will essentially entail site-specific approximations to fluctuating supply and demand situations, given the climatic dependence of agricultural production and long-term trends of productivity and overall economic development.

Environmental considerations will not be part of the equation if the proposed technologies are not economically viable. The fact that energy plantations recover the carbon dioxide produced by the combustion of vegetable fuels does not render diesel fuel unattractive for potential users if it is available at a competitive price. The subsidization of otherwise uneconomical fuels (fossil as well as biofuels) distorts the true market opportunities that exist for given energy solutions. The concept of sustainability, however, insinuates that the successful dissemination of solar technologies be based on an undistorted market and the active participation of target groups in the development of alternative energy technologies. Environmental protection and counteracting further resource degradation are, however, factors that may render renewable energy sources and non-polluting technologies truly economical when externalities, e.g. the societal costs of environmental goods or their rehabilitation, enter the equation.

It follows from the above that effective dissemination strategies would have to include, besides conducive technology policies allowing for pro-active development, acquisition and adaptation of solar technologies, measures to ensure the active participation of all stakeholders (policy makers, private sector, end users) to capture the economic, environmental and social aspects of energy technologies and to instigate the institutional sustainability needed to make a positive and lasting impact on current patterns of rural energy supply.

From the technological point of view, adoption constraints are mainly in the areas of high costs, standardization and quality control of available equipment. These are all factors amenable to further research and development and particularly to a closer cooperation between research and end-users. Successful dissemination further requires adequate repair and maintenance services which are commonly lacking in rural areas.

In many countries, there seems to be an institutional authority "vacuum" in relation to rural energy development. Agricultural and rural development authorities rarely have the capability or even the role to assess energy requirements and rely on the national utility companies to provide the necessary inputs. National energy authorities, however, give low priority to the rural sector because of its limited impact on the overall energy balance. It has been mentioned earlier that there is usually a serious underestimation of the actual rural energy consumption. Awareness needs to be created at the national level to look more critically at the linkages between rural development and energy needs.

The most serious barrier to dissemination, however, seems to be the absence of credit lines for the typical small-scale operation, especially for the purchase of energy technologies which are not considered productive. This is rooted in the recurrent obliviousness to the catalytic role energy plays in increasing yields, incomes and food security through ensuring timely operations. Initial investments for technical equipment are often too high for such small-farmers who are not deemed solvent by credit institutions. Solutions to this problem would include the integration of the private sector into rural credit systems, the abolition of import taxes on technical equipment, and the creation and support of cooperative structures to create and channel accumulated purchasing power and demand in rural areas. Opportunities may also exist for domestic manufacturing of equipment components, offering at the same time potential employment benefits.

There is also a certain imbalance that can be observed in the payments made by urban and rural users: while the former, being connected to the electric grid, pay only for the actual energy delivered (with the nation as a whole paying for most of the investment required), farmers outside this connection pay the total costs of installation. This would seem to severely inhibit the spread of rural energy systems (1).

In conclusion, energy policies are largely non-existent in rural areas of developing countries, which continue to be isolated from the main energy development efforts. Data are poor and unreliable and no pricing policies exist. There is usually no single institution responsible for energy decision-making, and the prevailing low level of economic activity makes public and private financing difficult. Approaches to rural energy technology dissemination have to take into account the small-scale nature of energy requirements, the lack of any systematic approach to energy management, and the absence of institutional infrastructure. The high-tech options that are becoming available, and the policies and taxes that are being set in place to reduce CO_2 and other emissions in industrialized countries and modern sectors of developing countries where the energy-environment relationship is well understood, are all entirely lacking in rural areas of developing countries. What is needed is an integration of rural and agricultural sectors into the modern development thrust of national energy development, which includes incorporating environmental considerations of both local and global scale. Activities have to be geared to developing methodologies and formulating strategies that will improve energy management and guide energy investment decisions. Advantage has to be taken of decentralized energy technologies based on a mix of conventional and solar sources. Through this approach, the transition from the present reliance on wood, animal and human power towards a more diversified and sustainable energy base can be facilitated (2).

5. RECOMMENDATIONS AND PROPOSALS FOR AN INTERNATIONAL COOPERATIVE PROGRAMME

Following below is a set of recommendations and proposals that merit attention at both the national and the international level. All proposals are, to varying degrees, relevant to most situations, depending on the stage of development, the nature and extent of energy supply problems and the action already taken. The proposals are kept broad enough to serve as guidelines for further elaboration in specific situations. Each proposal should be seen as a component of an overall strategy which culminates in the formulation of holistic policies and, where necessary, in multi- or bilateral technical and financial assistance to rural "energization"[2].

(i) Creating awareness among policy and decision makers

It is suggested that a strategy for rural energization with emphasis on the potential role of solar energy should start with the sensitization of policy makers for the problems of rural energy supply and demand in the overall context of national energy planning and rural development. This is ideally a task for national scientists and technology transfer agents, familiar with the

[2] The term 'energization" is utilized to stress that rural areas require a variety of energy forms and not only electricity as is normally the focus of many ongoing programmes.

actual constraints in rural development due to non-existing or biased energy policies. Policy makers and scientific advisors are the link to political support and commitment which. is vital for improved and sustained energy policies. National as well as international efforts should aim at the establishment or the strengthening of rural energy task forces or planning units, incorporating the different relevant sectors for rural development as well as regional and local representatives of rural energy committees/units etc.

(ii) **Institution building and strengthening**

Rural energy task forces or planning units should be empowered with the authority to submit national rural energy plans, based on iterative analyses of past and future energy flows and regularly updated information on technological options. This would require efforts in capacity building, both in technical/analytical and planning issues. The swift integration into existing administrative government structures has to be ensured. This is particularly important in the context of effective implementation and sustainable impact of rural energy policies. Furthermore, the current trend to privatization in many countries is leading to a diminishing role of governments in traditional public sectors. The regulatory function of governments, however, should be sustained and consolidated to safeguard the interests of the poorest sections of the population.

(iii) **Sectoral integration and decentralization**

The traditional separation of the relevant sectors, particularly energy on the one hand and agriculture and rural development on the other, contributes significantly to inconsistent or non-existing policies for rural energy. National rural energy units, therefore, should strive to overcome this partition and consolidate isolated or overlapping activities in energy planning. Besides agriculture (i.e. research, extension, rural development, local organizations) and energy, this includes naturally forestry, fisheries and environment, as well as NGOs. Decentralization of planning efforts into consortia according to regional or agro-ecological criteria should also be encouraged where national budgets are too small to deal with local issues, which is rather the rule than the exception. The motivation for project implementation often lies at the local level and decentralized units are tools for local groups to design and implement their own energy and development plans.

(iv) Participatory approaches to rural energization

The determination of local needs and aspirations is as important as the overall administrative and legislative set-up. Efforts have to be made to sensitize local populations about energy issues and their participation and active cooperation has to be sought in the planning process. Much has been said about target group participation and its relevance for project or programme design and implementation. The crucial issue seems to be the empowerment of rural populations to determine the course of action, which should be reflected in the degree of influence they can exert on energy planning decisions: local priorities have to find their way into the upstream planning through the integration of villages, districts or municipalities as basic units in the institutional arrangements. Participation should extend to monitoring and evaluating in order to learn from experiences, to create an atmosphere of mutual trust between planners and recipients and to jointly change the course of action, if necessary. This general approach is relevant for both the dissemination of "mature" technologies with some need for local adaptation, and for the collaborative generation and development of location-specific energy technologies. Cooperators on the government side should include research as well as development actors.

(v) Assessment of energy flows

The assessment of energy flows at local levels would be one of the first tasks of energy planning units. Energy surveys in combination with macro-economic data can be used to obtain aggregate rural energy balances and to identify priority areas requiring urgent action. The studies should be comprehensive in scope and disaggregate supply and demand patterns related to household, agriculture and agro-industry energy needs.

Surveys would have to include, besides supply and demand assessments, detailed analyses of the spatial and temporal variation of energy needs and supplies, e.g. the decentralized nature and small scale of user units, the potential of available and wasted resources (e.g. residues), the impact of certain technology options on sustainability issues (e.g. resource base protection, overall rural development), and the available and needed infrastructure and services. Such analyses should not omit an assessment of investments needed, both at individual users' and at the sectoral level as well as an estimation of expected benefits. Here, care should be taken to capture non-pecuniary issues and to internalize the externalities in order to arrive at realistic estimates of societal costs and benefits. This would serve to base energy investment decisions on cost/benefit analyses, to assess the need for and scope of credit supply, to facilitate evaluation of impact against initial projections, and, last but not least, to mobilize national resources and to tap on funds from potential bi- and multilateral donors.

(vi) **Quantitative case studies on impact of rural energy supply**

Rural energy flows should be complemented by efforts to quantify energy supply impact on agricultural productivity, quality of rural life, food security and employment opportunities in specific locations. The linkages between energy and agriculture are often poorly understood and such case studies would be valuable to decision makers when assessing the potential benefits of rural energy interventions.

(vii) **Strengthening R & D**

R & D cooperation is needed at two distinct levels: the national context requires a closer integration of the different actors involved, i.e. research, technology transfer (extension, private sector), and end-users (individual users, local groups); at the international level, cooperation should be sought between developed and developing countries as well as among developing countries.

Three priority areas for solar energy technology R & D can be identified: (a) increased cost-effectiveness through lower production costs, higher productivity and better conversion efficiency; (b) compatibility with both environmental and food security issues (this refers mainly to the potential conflict between energy plantations and food production and the need to base biofuel production on the concept of comparative advantages, i.e. the beneficial effects on rural and agricultural development, biodiversity protection, reduction in atmospheric gas emissions, and land rehabilitation); and (c) the social aspects of energy technologies, i.e. acceptability, dissemination strategies and related price policies. All R & D efforts would benefit from participatory and collaborative approaches embracing the relevant actors, including policy makers.

(viii) **Creating, identifying and strengthening local domestic manufacturing capacities**

One of the major impediments to wider solar energy technology dissemination are the initial costs of equipment which often has to be imported due to the lack of local manufacturing capacities. Local production of components could significantly contribute to lower costs for installation of technical equipment, while at the same time increasing rural non-agricultural employment opportunities. Support to local manufacturing capacities should form an integral part of national and international programmes for the promotion of solar energy.

(ix) **Facilitating international energy technology transfer**

The lack of access to technology developed elsewhere is an often voiced criticism by developing countries. Many programmes and projects exist in this area but, nevertheless, opportunities remain unexploited because of export/import restrictions. Solar technologies are being generated by several developed as well as developing countries, and significant progress has been made during recent years, partly due to the increased emphasis on environmental friendliness of energy production and partly as strategic solutions to future changes in fossil energy supply and prices. Such technologies, however, tend to be suited to distinctive needs and possibilities and require adaptive research for their application in different environments. Technology transfer and adaptation need to be seen as complementary efforts.

(x) Assistance to holistic policy formulation

Policy formulation is probably the area with the greatest need for assistance. A multi-facetted approach is needed that incorporates and streamlines all the above mentioned aspects in a forward-looking manner. In many countries, there appears to be a dearth of institutional capacity to take on this task. While national governments have to put in place or consolidate institutions for policy design and monitoring of implementation, multi- and bilateral organizations can play a prominent role in assisting in the policy formulation process, once the perceived needs lead to explicit commitment at government level.

There is, however, a wide array of international policy matters to be resolved before global issues of patterns of energy use and its linkages to environmental problems will be reflected in national policies. The global concern about checking and reversing current trends of deforestation in some parts of the world is but one example for conflicting international and national interests.

To recapitulate the above, conducive policies would have to be designed along appropriate guidelines for streamlining institutions, integrating sectors and local organizations, assessing and planning demand and supply, supporting R & D and local manufacture, and deriving maximum benefit from imported technology through technology assessment. To encourage the adoption of solar energy technologies by producers, financial policies should promote deregulation and provide incentives. Viable credit schemes for solar technologies should be considered among them. High priority should be given to energy price reforms, introducing fair prices for fossil fuels, biofuels and electricity, by internalizing resource base degradation and pollutant emissions. Project activities should be the result of coordinated policy formulation at the national level.

(xi) Assistance to rural energization project implementation

FAO has been called upon to assist in the translation into action of the energy activities outlined in the relevant Chapters of Agenda 21, mainly Chapters 9 and 14 [k] (Rural energy transition to enhance productivity). To this end, FAO's activities in this area are aimed at the transition from the present energy supply of mainly firewood and animal and human power to a more diversified base and better use of commercial and renewable energy. Technical assistance is guided by the following principles:

1. energy inputs are key to sustainable development;
2. agriculture, forestry, and fisheries have a role and potential as both energy consumers and sources of renewable energy;
3. coordination between energy and agricultural plans is required;
4. efficient energy use and utilization of a mix of both commercial and renewable sources are basic elements of the required energy transition;
5. decision-making for energy investments in rural areas requires enhanced participation of local populations;
6. international cooperation is necessary to strengthen national capabilities.

Field activities of FAO are in the areas of assessment and planning, fuelwood and charcoal, biomass, biogas, gasification, rural mechanization, solar energy, wind energy, small hydropower systems, draught animal technology, integration of energy sources, and information dissemination.

Continued international cooperation and mobilization of international resources are required for the acceleration of agricultural and rural development through increased energy inputs. FAO provides technical assistance to countries in their efforts to consolidate energy development for rural areas and gives priority to the development of renewable sources, in close cooperation with the UN and its specialized agencies, with international, national, non-governmental and inter-governmental institutions. In particular, FAO continues its efforts to strengthen developing countries' technical capabilities for the management and implementation of energy activities leading to sustainable rural development (1).

(xii) Consolidating the role of the UN as the political information and technology exchange forum

The UN is in a unique position to provide unbiased information and technical advise and, consequently, facilitate international exchange of energy technologies. UN specialized agencies are active in this area in their respective fields of expertise. There is a need within the UN for the coordination of cross-sectoral activities such as rural energization, and for the creation and promotion of awareness at national, regional, and sub-regional levels. In particular, the UN offers the best forum for international dialogue on the main policy areas guiding these activities. In a growing interdependent world, the UN must play its role in energy matters which is probably the single most important technical field affecting all societies. Solar energy requires concerted international action if its potential is to be effectively mobilized.

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CHAPTER 5.

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SUMMARY

Agriculture continues to be the main activity of millions of rural people in developing countries, providing the food and services without which societies would not survive. Yet, inputs to agriculture, necessary to enhance productivity and reduce human drudgery continue to be absent in rural areas, at least in a scale commensurate with the requirements. For the majority of farmers in developing countries, their own muscles, sometimes assisted with the power of animals and with rudimentary utensils and tools, continue to provide the mechanical energy to carry out the agricultural production cycle. The lack of fertilizers, pesticides and irrigation equipment contributes to the low efficiency of agriculture, leading in many places to food production levels dangerously below the minimum required to sustain society. The problem is further exacerbated by the food losses due to a lack of processing and conservation facilities.

The Report discusses the linkages between energy and agriculture, highlighting the gap between potential and actual productivity of the agricultural sector due to the lack of inputs, focusing on the particular role of energy in this respect. The present energy situation in agriculture is discussed, and opportunities are identified for solar energy's contribution to the lifting of agricultural productivity.

Under the new international environmental agenda, sustainable agriculture is perceived as a requirement to future survival of Humanity. The concept of sustainability, nevertheless, acquires special significance when dealing with a sector of society which has been generally left out of the socioeconomic thrust enjoyed by the more modern sectors. Investments for both agriculture and energy have, in most countries, been below the level necessary to warrant social stability and economic development. The challenge facing many developing countries is how to fulfil the energy needs of agriculture in an economic and sustainable manner, taking into full consideration and with a balanced strategy, the developmental and environmental issues which govern policy and technical interventions. In this respect, the Report highlights the growing role of agriculture as a producer of renewable biomass energy in the form of liquid, gaseous or solid fuels.

Making reference to the ample bibliography which exists in the technological field, the Report assesses the opportunities for utilization of solar, wind and biomass energy resources, considered the most promising for rural areas. While giving due recognition to the important role of technology, the Report stresses the need for innovative policies and strategies in the planning, institutional and financial energy fields. It identifies major barriers to a more widespread use of those resources and presents a series of recommendations designed to effectively and urgently mobilize action towards the full integration of the solar energy potential in efforts to achieve sustainable agriculture, the ultimate objective. Finally, the Report identifies areas for international collaboration which could make an important contribution in this respect.

RESUME

L'agriculture reste la principale activité de millions d'habitants des zones rurales dans les pays en développement et elle fournit les aliments et des services sans lesquels les sociétés ne survivraient pas. Malgré cela, les investissements et intrants qui seraient nécessaires pour améliorer la productivité de l'agriculture et rendre la vie des agriculteurs moins difficile continuent d'être très insuffisants dans les zones rurales. Pour la majorité des agriculteurs des pays en développement, la seule énergie mécanique dont ils disposent pour exploiter la terre est celle de leurs muscles, parfois complétée par celle d'animaux, et aidée par des ustensiles et des outils rudimentaires. Le manque d'engrais, de pesticides et de matériel d'irrigation limite la productivité de l'agriculture, si bien que dans de nombreux endroits la production alimentaire reste bien inférieure au minimum nécessaire pour nourrir la société. Ce problème est aggravé par les pertes dues au manque d'installations pour la transformation et la conservation des produits alimentaires.

Le rapport examine les liens entre énergie et agriculture, mettant en évidence l'écart entre la productivité potentielle et la productivité réelle du secteur agricole, qui est dû à l'insuffisance des intrants, et souligne, à cet

égard, le rôle particulier de l'énergie. Il examine la situation actuelle de l'énergie dans l'agriculture et décrit les différentes options envisageables pour mettre l'énergie solaire au service de l'amélioration de la productivité agricole.

Dans le cadre des nouvelles préoccupations internationales concernant l'environnement, la durabilité de l'agriculture apparaît comme une des conditions de la survie future de l'humanité. Toutefois, le concept de durabilité prend un sens particulier s'agissant d'un secteur de la société qui a généralement été laissé à l'écart des progrès socio-économiques réalisés dans des secteurs plus modernes. Dans la plupart des pays, les investissements dans l'agriculture et le secteur énergétique sont restés inférieurs au niveau nécessaire pour assurer la stabilité sociale et le développement économique. Pour de nombreux pays en développement, le problème est de répondre aux besoins énergétiques de l'agriculture de façon économique et appropriée, en tenant pleinement compte, dans le cadre d'une stratégie équilibrée, des critères de développement et de protection de l'environnement qui doivent présider à la définition des politiques et aux interventions techniques. A cet égard, le rapport met en évidence le rôle croissant de l'agriculture dans la production d'énergie renouvelable, grâce à la transformation de la biomasse en combustibles liquides, gazeux ou solides.

Renvoyant à une importante bibliographie technique, le rapport évalue les possibilités d'utilisation de l'énergie solaire et éolienne et de l'énergie de la biomasse, qui sont considérées comme les plus prometteuses pour les régions rurales. Tout en reconnaissant l'importance du rôle de la technologie, le rapport souligne la nécessité d'appliquer des politiques et stratégies novatrices en matière de planification, d'encadrement institutionnel et de financement dans le domaine de l'énergie. Il identifie les principaux obstacles qui s'opposent à une utilisation généralisée de ces ressources et présente une série de recommandations visant à mobiliser efficacement et rapidement des ressources pour exploiter l'énergie solaire au service d'une agriculture durable, qui est l'objectif ultime. Enfin, il définit les secteurs dans lesquels la collaboration internationale pourrait apporter une contribution importante à cet égard.