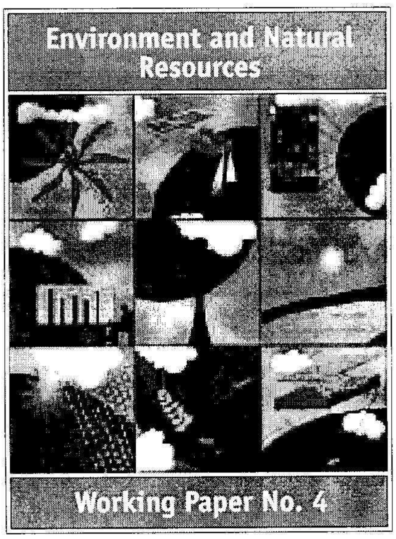
Environment and Natural Resources Service
Sustainable Development Department



THE ENERGY AND AGRICULTURE NEXUS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2000

The Energy and Agriculture Nexus

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Abstract

Energy has a key role in economic and social development but there is a general lack of rural energy development policies that focus on agriculture. Agriculture has a dual role as an energy user and as an energy supplier in the form of bioenergy. This energy function of agriculture offers important rural development opportunities as well as one means of climate change mitigation by substituting bioenergy for fossil fuels. This report focuses on the challenges and opportunities of advancing modern bioenergy technology, in general, and on the technical, environmental and economic benefits of the energy function of agriculture, in particular.

This report has been prepared as a contribution of FAO to the 9th Session of the Commission on Sustainable Development which will meet in April 2001 and its follow-up, which is expected to accelerate the global move towards more sustainable energy systems.

Keywords: Energy; Agenda 21; Commission for Sustainable Development – CSD; rural development; agriculture; bioenergy; sustainable energy systems; energy indicators; Kyoto Protocol.

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Foreword

This report has been prepared as a contribution by FAO to the work of the ninth session of the United Nations Commission on Sustainable Development (CSD-9), to be held in April 2001, where the sectoral theme of Atmosphere/Energy and the economic theme of Energy/Transport will be discussed.

The report examines the links between energy and agriculture. It highlights the dual role of agriculture as an energy user and as an energy producer. This dual function implies greater agricultural productivity on the one hand, and higher levels of energy sustainability through the production of CO_2-neutral bioenergy on the other. As the international community discusses ways and means to achieve more sustainable energy systems, it is vital to recall that around two billion people in the world are still energy-starved. There are many rural people in developing countries who rely on meagre energy inputs for their subsistence needs, with little or no energy available for productive or income-generating activities. A transition to more sustainable rural energy systems is urgent, and CSD-9 could make an important contribution in this respect. A more extensive use of bioenergy will lead to considerable benefits to the global environment and to the development of local infrastructure, but the potential conflicts with food production and impacts of land use change must be followed closely. FAO is currently strengthening its bioenergy programme with the aim of contributing to a partial substitution of fossil fuels by biofuels. The report will add to the discussions on the above issues by providing the latest thinking, examples and data, while avoiding being prescriptive.

The report was coordinated by Mr Gustavo Best, and was prepared with the assistance of Mr David Martin, to whom we express our sincere appreciation for his dedication and interest. Special thanks also go to Messrs Michele Bernardi, Tudor Botzan, Bart van Campen, He Changchui, Lawrence Clarke, Theodor Friedrich, Torsten Frisk, René Gommes, Peter Griffee, Wulf Killmann, Ali Mekouar, Morton Satin, Peter Steele and Miguel Trossero, who provided inputs and comments during the different stages of preparation of the report. FAO gratefully acknowledges the support provided by the UK Permanent Representation to the United Nations Agriculture Agencies in Rome and by the UK Department for International Development (DFID), which made the preparation of this report possible.

FAO hopes that this study will contribute to a much needed change in the energy scenario of rural areas in developing countries and, most important, to greater concerted and consolidated international actions towards global energy sustainability. FAO looks forward to the CSD-9 deliberations and, in particular, to its follow-up.

Jacques Eckebil
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Glossary and Definitions

AIJ	Activities Implemented Jointly: greenhouse gas reduction projects implemented in some countries that are parties to the UNFCCC, which are funded from other parties, but without any crediting of emissions.
Annex 1	The industrialized countries and economies in transition undertaking specific commitments under the UNFCCC and the Kyoto Protocol.
Bioenergy	Bioenergy is used as the term for energy generated from biofuels, and does not include human or animal work. It covers all energy forms derived from organic fuels of biological origin used for energy production; it comprises both purpose-grown energy crops and multi-purpose plantations and by-products (residues and wastes). The term by-products includes solid, liquid and gaseous by-products derived from human activities. Biomass may be considered as one form of transformed solar energy. (Further detailed definitions of related bioenergy, biofuels and biomass terms are contained in the Annex).
Biofuels	Biofuels are fuels of renewable and biological origin, including woodfuel, charcoal, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, agricultural wastes and by-products, and energy crops.
Biomass	Biomass is defined for the purposes of this report as all forms of plant-derived matter other than that which has been fossilized.
CDM	Clean Development Mechanism, as proposed in the Kyoto Protocol: CDM governs project investments in developing countries that generate certified emission reductions for industrialized countries undertaking specific commitments under the UNFCCC and the Kyoto Protocol.
CER	Certified Emissions Reductions: as proposed for the Clean Development Mechanism, CERs can be earned with a CDM project in a developing country and added to the assigned amounts of an Annex 1 country.
CSD	Commission for Sustainable Development of the United Nations.
Developing countries	In this report, developing countries are taken to comprise all countries in Africa, Asia (excluding Japan), Latin America and the Caribbean, and Oceania (excluding Australia and New Zealand).
ERU	Emission Reduction Units: as proposed for Joint Implementation, ERUs can be earned by an industrialized country with a JI project in an economy in transition.
GEF	Global Environment Facility: the international financing mechanism providing incremental funding for projects with global environmental benefits, jointly implemented by UNDP, UNEP and the World Bank.

GHG	Greenhouse gases: The gases covered by the Kyoto Protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perflourocarbons and sulphur hexafluoride.
GDP; GNP	Gross Domestic Product; Gross National Product.
JI	Joint Implementation, as proposed in the Kyoto Protocol: JI governs project investments implemented between two Annex 1 countries. It allows for the creation, acquisition and transfer of emission reduction units. (In practice this is likely to involve investments in economies in transition that generate emission reduction units for industrialized countries undertaking specific commitments under the UNFCCC and the Kyoto Protocol).
kN	kilo-newton, a unit of force, used in this report to measure pulling force by humans or animals.
kW; MW	kilowatt; megawatt: units of power, used in this report to measure electrical (when designated kWe, or MWe) or mechanical power output from an energy generating device, or the power demand of an energy using device.
kWh	kilowatt-hour, a unit of energy, used in this report to measure electrical or mechanical energy.
Kyoto Protocol	The international agreement to address the threat posed by the steady accumulation of heat-trapping greenhouse gases in the earth's atmosphere.
IEA	International Energy Agency.
IPCC	Inter-governmental Panel on Climate Change.
MFCAL	Multi-functional character of agriculture and land.
OECD	Organisation for Economic Cooperation and Development.
PCF	Prototype Carbon Fund, established by the World Bank to invest in projects that produce greenhouse gas emissions that can be registered with UNFCCC for the purposes of the Kyoto Protocol.
PV	Photovoltaic systems, that convert solar radiation directly into electricity using specially prepared semi-conductors.
Renewable energy	Consists of energy produced and/or derived from sources infinitely renovated or generated by combustible renewable sources. The main forms of renewable energy are solar, wind, biomass, hydro, geothermal and ocean energy.

SARD	Sustainable Agriculture and Rural Development.
tC(e)	tonnes of carbon (equivalent): used as a common unit for the weight of emissions of each of the greenhouse gases covered by the Kyoto Protocol, related to the global warming potential of CO_2.
Technology transfer	Technology transfer, established in the UNFCCC and the Kyoto Protocol is one of the instruments for transfer of Annex 1 technology to the developing countries for their sustainable development.
toe	tonnes of oil equivalent: often used as a common unit for the energy content of different fuel sources. 1 toe is 42 GJ.
UNDP	United Nations Development Programme.
UNEP	United Nations Environment Programme.
UNFCCC	United Nations Framework Convention on Climate Change.
WEC	World Energy Council.
Wood energy	Energy derived from primary and secondary solid, liquid and gaseous biofuels derived from forests, woodlands and trees. Wood energy represents the energy produced by combustion of woodfuels, such as fuelwood, charcoal, pellets, briquettes, etc., corresponding to the net calorific value of the fuel. (Further definitions of wood energy and related topics are contained in the Annex).

Executive Summary

In line with the work of the Commission on Sustainable Development (CSD), Agenda 21 and other energy-related international agreements, FAO has emphasized the integration of energy with agricultural policies, as a means of working towards the sustainable and rational use of energy in agriculture[1]. The purposes of this report are to examine the links between energy and agriculture in terms of the energy requirements for greater agricultural productivity in developing countries; the energy needs of rural populations; and the CO_2 mitigation (substitution) function that agriculture can provide in the form of biomass[2]. The CSD-9 session in April 2001 will include the sectoral theme atmosphere/energy and the economic theme energy/transport. The report draws from the latest thinking and advancements in the analysis of energy and agriculture and is submitted as a contribution of FAO to the CSD-9 process and its follow-up.

Energy has a key role in economic and social development

It is a paradigm of development policy that without appropriate energy services there can be no true economic development, yet around 2 billion people world-wide do not have access to modern forms of energy. Aid in support of national efforts includes a variety of rural energy programmes to improve energy provision, often through rural electrification. Decoupling growth in energy consumption per capita from economic growth and focussing on the appropriate provision of quality energy services to assist economic development is now seen as key to future evolution of the energy sector. Increased access to energy services can help reduce poverty, but much of the effort thus far has focussed primarily on household energy use, with less attention being paid to energy services for rural industries and agriculture.

Energy has a major impact on the global and local environment

Agenda 21 and the UNFCCC have highlighted the adverse local and global impacts of energy supply and end-use on the environment. The needs of sustainable development and the use of clean energy technologies are well recognised. Actions at national and international levels to tackle the problems of air quality and climate change are being developed, and these will require new directions for both energy policy and technology and the nature of investment decisions in energy supply and end-use systems. Energy projects in developing countries have the opportunity to benefit from funding via the Global Environment Facility, and for their promoters to participate in the Clean Development Mechanism. These instruments offer the prospect of further international cooperation in rural energy development in order to achieve environmental, social and economic goals.

Insufficient modern energy is available for agriculture and this affects food security

In agriculture, a wide range of modern and traditional energy forms are used directly on the farm, e.g. as tractor or machinery fuel, and in water pumping, irrigation and crop drying, and indirectly for fertilizers and pesticides. Other energy inputs are required for post harvest processing in food production, packaging, storage, transport and cooking. Direct energy use in agriculture accounts for only a relatively small proportion of total final energy demand in

[1] This report uses the generic term 'agriculture' to cover agricultural, livestock, forestry and fishery activities.

[2] The report does not examine the CO_2 mitigation function that agriculture provides in the forms of carbon storage in forestry or carbon soil sequestration.

national energy accounts[3]. In OECD countries, the figure is around 3-5%, and in developing countries between 4-8%. Energy for agricultural practices in many developing countries continues to be based to a large extent on human and animal energy, and on traditional woodfuels. Empirical evidence suggests that the potential gains in agricultural productivity through the deployment of modern energy services are not being fully realized in developing countries. This reduces both the quantity of food produced, and also the quality of food. Rural people are sometimes forced to eat either uncooked food or food that can easily be cooked but which may not give full nourishment.

There is a general lack of rural energy development policies that focus on agriculture

Many energy policies and interventions in developing countries are designed for the needs of industry, transport and urban infrastructures, whilst agricultural energy requirements are frequently overlooked. Although agriculture contributes significantly to economic and social development, often accounting for around 30% of developing country GDP, energy provision in agriculture has not received the attention that the sector deserves. Energy for agriculture needs to have a higher priority in rural policy and technology assessment work in developing countries than has been the case hitherto.

Bridging the energy gap by improving rural energy services

The analysis in the report shows that there is an energy gap in the agricultural sector that needs to be bridged. Extending grid electrification into rural areas can bring social and economic benefits, but for many rural communities there is no immediate prospect of being connected to the central electricity grid, and other commercial energy sources are often too expensive for poor people. Where electrical load densities are low, off-grid diesel generators can be cost-effective. Another means of tackling this is to make use of the energy resources that are available locally to rural populations through modern renewable energy systems. These include improved modern biomass conversion to generate electricity, and to produce heat and liquid fuels. Other renewable energy sources such as solar energy, wind and small-scale hydropower can also be exploited.

Potential energy savings can also be made through changes in the design and use of tractors and other farm machinery and improvements in irrigation, drying, livestock production and horticulture. Conservation tillage, which involves little mechanical tillage, is an approach to reverting soil degradation by promoting soil organic matter through permanent soil cover. Improved energy efficiency in mechanical handling equipment and in drying and separating operations is also important. Attention to these factors can help achieve a greater degree of self-sufficiency in developing countries, by reducing the need for imports of fossil fuels, and promoting the development of locally sourced energy supplies.

An energy transition is needed in rural areas

Given the spread of technology and general economic development, it can be expected that traditional energy technologies will co-exist with a gradual improvement and introduction of new technologies accompanying the rural development process. There is also the prospect of

[3] Excluding the energy used in food processing, packaging, transport and storage, and traditional energy sources such as woodfuel.

technological 'leapfrogging' which could give developing countries the chance to commercialize new technologies relatively quickly. But there is a need for more urgent action, due to the low rate of economic improvement in many rural areas and the drift of rural populations to peri-urban and urban areas in developing countries. Agriculture can have a major role in supporting sustainable rural livelihoods through the increased provision of locally sourced bioenergy. Such an approach can assist more broadly in rural development as well as improving food security.

The energy function of agriculture should be exploited

The role of agriculture as an energy supply resource is a crucial factor in taking forward this energy transition, and, indeed, in achieving higher sustainability in the rural areas of industrialized countries. The provision of locally sourced energy through the exploitation of energy crops in modern biomass systems could give an attractive means of stimulating rural economic development, whilst at the same time offering an option for improved energy supply. Agriculture can also make a major contribution to climate change mitigation by CO_2 substitution since biomass is a carbon-neutral energy source over a short time scale. Biomass offers the prospect of fulfilling a dual role by combining sustainable development in rural areas and climate change mitigation. Projects funded via the Global Environment Facility, Joint Implementation and the Clean Development Mechanism could make use of agriculture's contribution to global climate change mitigation and give local economic, social and environmental benefits. Agriculture's contribution as a carbon-neutral energy resource should be exploited as one solution in conjunction with other greenhouse gas emission control technologies.

Advancing modern bioenergy technology

Large-scale production of bioenergy would initially require the use of agricultural and forest residues, and eventually dedicated energy crop plantations. The cost-effectiveness in any particular investment situation is likely to depend on site-specific opportunities. The long-term effects of bioenergy exploitation, through dedicated plantations, on soil quality, fertility and biodiversity may be adverse. There are also potential conflicts with other land uses. But the CO_2 substitution opportunity may tip the balance in favour of bioenergy investments if they are regarded as being of global importance, especially if GEF funding, or appropriate value for ERUs and CERs for bioenergy projects obtained through Joint Implementation and the Clean Development Mechanism, can be used to support the investment costs.

There is, therefore, a balance to be struck between the advantages and disadvantages of bioenergy, and this is reflected in both optimistic and pessimistic views regarding the uncertainties about how bioenergy systems can provide cost-effective local and global benefits. These uncertainties have restricted the development and commercialization of modern biomass technologies. However, with the significant environmental pressures to redirect the global energy economy onto a more sustainable path, there is a real and urgent need to reconsider policy choices and commitments in the energy sector. Actions to take the energy sector in new directions are vitally important, and the proposed steps listed below are a first stage in this process, which is applicable to the rural energy sector of developing countries.

It is clear that considerable efforts are needed in order to take forward the energy-agriculture nexus. The technological, environmental and social dimensions need to be further developed and assessed. It is hoped that, by drawing the attention of the CSD-9 to the potential of this nexus, and describing the advantages and disadvantages of modern biomass technologies, areas for action can be identified and implemented through cooperative efforts within the international community and with host developing countries.

A challenge and an opportunity

An integrated approach which exploits the synergies and dual role of agriculture as an energy user and an energy supplier needs to be developed. The links that energy and agriculture can make between sustainable rural livelihoods, local environmental protection and global environmental benefits are important issues to address. In order to mobilize the synergies and develop the energy function of agriculture:

- the role of agriculture in providing both a source of renewable energy which contributes to rural economic development, and a substitute for fossil-fuels should be recognised and exploited in future energy policy formation and technology development;
- demonstration, research, training and capacity building projects that have the potential to deliver the energy function of agriculture in a cost-effective and market-oriented manner are required;
- there is the need for positive political encouragement and appreciation of the social and cultural changes that might be needed to develop this potential.

Actions should be taken to:

- ensure that rural energy projects are sustainable, by tackling and overcoming social, cultural, institutional, legal and financial barriers;
- avoid creating disincentives for investors or entrepreneurs to invest in rural markets for modern fuels and should put biomass and other renewable energy sources on more equal terms with fossil fuels;
- recognize the potential of bioenergy and renewable energy sources in general to assist both in the provision of energy services in the rural areas of developing countries and in the transition to more sustainable energy systems world-wide;
- include the prospect of private sector finance for sustainable bioenergy projects that have the potential for delivering the energy function of agriculture;
- develop joint programmes for making best use of the energy function of agriculture with national governments, bilateral and multilateral organizations, and with the private sector;
- JI, CDM projects or other flexible mechanisms agreed by the international community could make use of modern biomass systems. Bioenergy projects are already included in GEF activities. All these opportunities should be developed further;
- for the energy function of agriculture to play its full role, incentives will be necessary to put bioenergy on more equal terms with conventional fuels, and major R&D, technology development and policy gaps need to be addressed.

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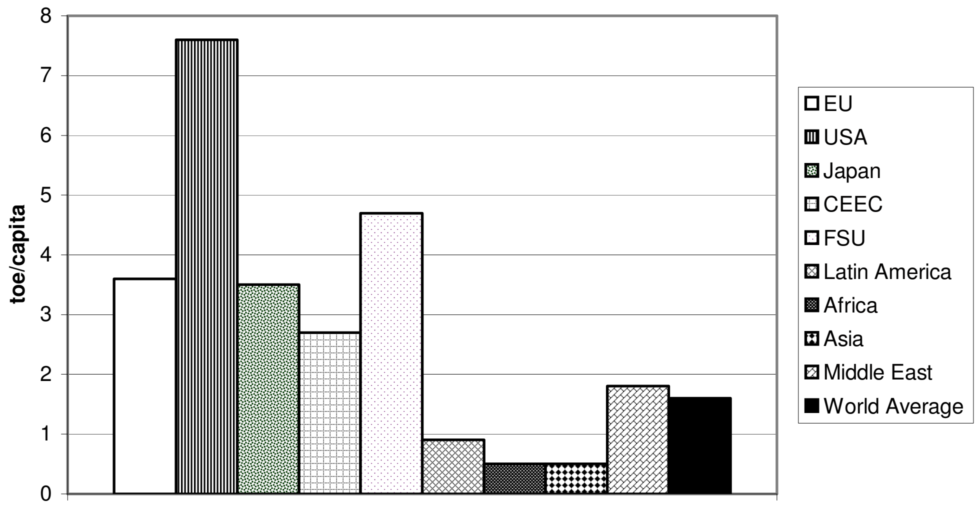
Chapter 1: Energy in the World Economy

1.1 Introduction

Energy is a foundation stone of the modern industrial economy. Energy provides an essential ingredient for almost all human activities: it provides services for cooking and space/water heating, lighting, health, food production and storage, education, mineral extraction, industrial production and transportation. Modern energy services are a powerful engine of economic and social development, and no country has managed to develop much beyond a subsistence economy without ensuring at least minimum access to energy services for a broad section of its population. Throughout the world, the energy resources available to them and their ability to pay largely determine the way in which people live their lives. Nevertheless, it is critical to recognize that what people want are the services that energy provides, not fuel or electricity *per se*.

Many factors play a role in influencing energy supply, not least of which are its availability, price and accessibility. The regional endowment of energy sources and the pace at which they are developed and distributed are not uniform around the world. Figure 1.1 shows annual primary energy consumption per capita in various regions of the world (WEC, 1993). The data indicate the wide variation between regions, not solely accounted for by climatic differences. Average world annual consumption at around 1.6 toe/capita; in OECD countries the average is around 5 toe/capita and in developing countries it is less than 1 toe/capita.

Figure 1.1: Primary Annual Energy Consumption per Capita (1990) toe/capita

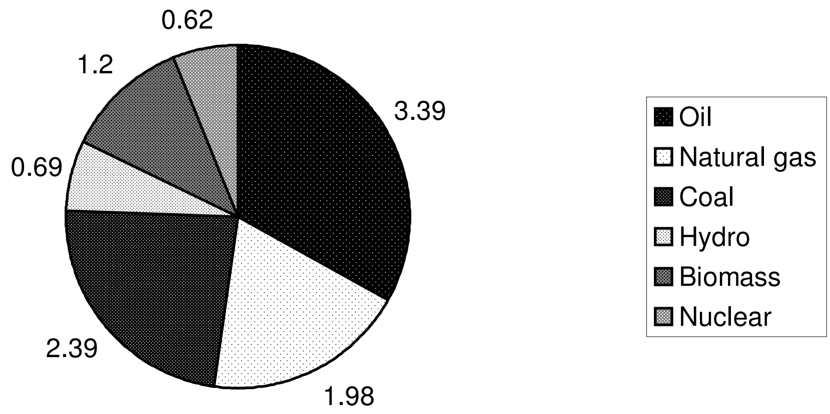


The last two centuries have seen massive growth in the exploitation and development of energy sources, and the world has gained many benefits from these activities. The magnitude of energy consumed per capita has become one of the indicators of development progress of a country, and as a result, energy issues and policies have been mainly concerned with increasing the supply of energy. This approach is now seen as a vision that needs challenging. Decoupling growth in energy consumption per capita from economic growth and focussing on the appropriate provision of quality energy services to assist economic development is key (UNDP, 1997; UNDP/EC, 1999; and World Bank, 2000b).

1.2 Fuel Types

World primary energy use remains dominated by fossil fuels (coal, oil and natural gas), which account for 75% of total primary energy supply. Renewable energy sources, comprising mainly biomass[4] (including fuelwood) and hydropower, currently represent less than 19% of world primary energy use, of which biomass contributes about 14%. Nuclear energy contributes around 6%. Figure 1.2 illustrates these data (BP, 1998).

Figure 1.2: World Primary Energy Use by Fuel Type, 1997 (Gtoe)



The patterns of energy use by fuel type and the way these patterns change over time in developing countries reveal further insights into exploitation of different energy resources. Figures 1.3, 1.4 and 1.5 show estimates of total final energy use by fuel type in Latin America, Asia and Africa respectively over the period from 1980 to 1995 (EC, 1999).

The role of biomass is of particular significance. Biomass use is unevenly distributed around the world: it represents 3% of energy use in industrialized countries and an average of 33% in developing countries, with large differences between regions: biomass covered over 60% of final energy use in Africa, 34% in Asia and 25% in Latin America. Other renewable energy sources, such as small-scale hydropower, geothermal, wind, and solar energy, do not feature as significant energy inputs. Worldwide the aggregated energy supply from these renewable sources amounts to less than 1% of the total. The data also indicate that the proportions of different fuel types changed little in developing countries between 1980 and 1995.

Households and communities in rural areas in developing countries typically rely on diverse sources of energy; using one fuel for heating, another for cooking or lighting and others for agricultural and other productive activities. Most biomass is consumed in traditional ways in the household sector, and is simply collected rather than purchased. Such fuels are locally 'free' in cash terms, but have a cost of much time and physical effort often by children and women. In some rural and urban areas, charcoal has become a cash crop contributing to a monetised economy, and in some urban areas, there are active markets in local woodfuels.

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[4] Biomass definitions and related terms, and further descriptions of the energy content of biofuels are contained in Annex A.2.

Figure 1.3: Total Final Energy Use in Latin America

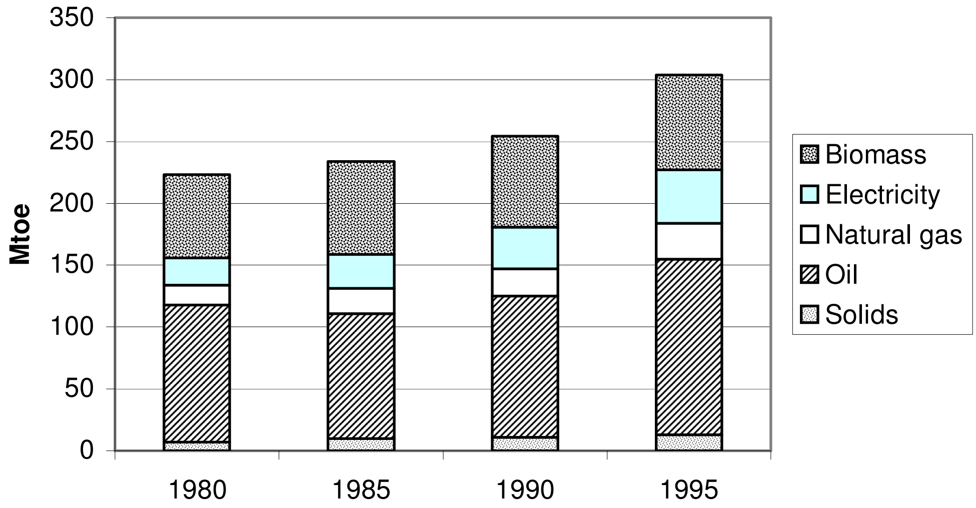


Figure 1.4: Total Final Energy Use in Asia

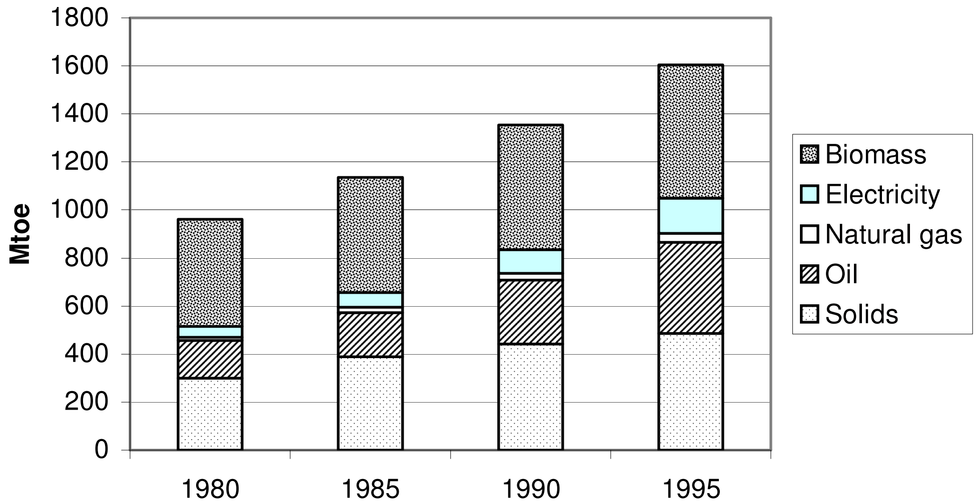
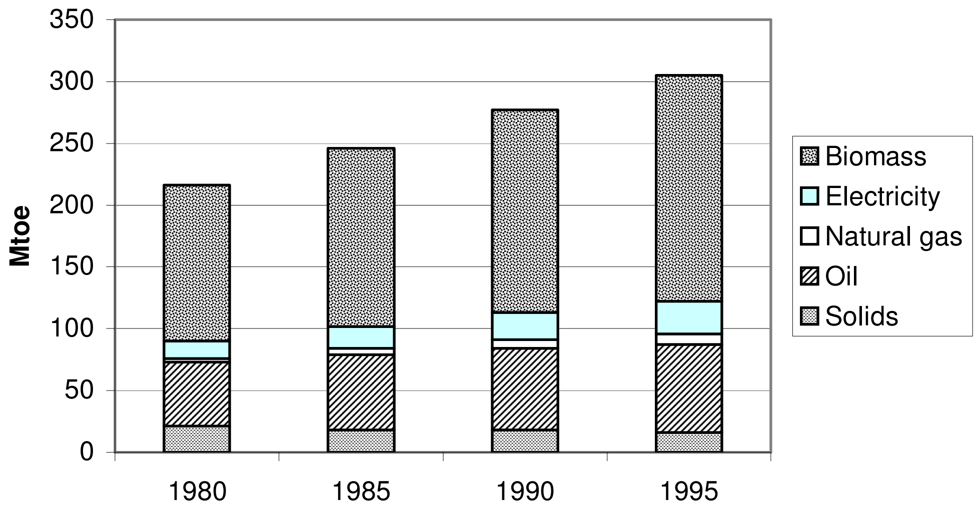


Figure 1.5: Total Final Energy Use in Africa

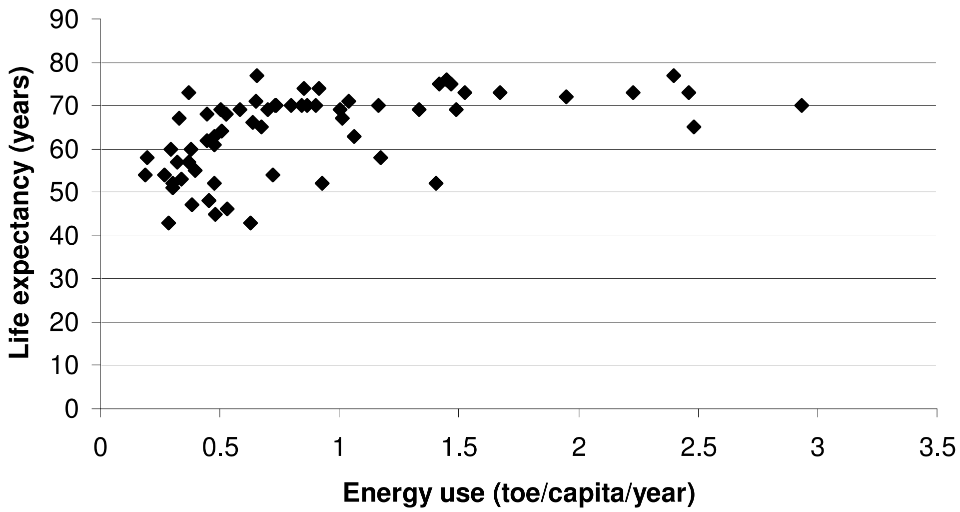


Because biomass remains such an important fuel around the world, energy policies for developing countries need to be as concerned with the supply and use of biomass, whether in its traditional role or used in modern technology, as they are about fossil fuels or other renewable sources of energy.

1.3 Energy and Development

In developing countries, it is widely accepted that poverty will not be reduced without greater use of modern forms of energy. Surpassing the 1 toe/capita per year level of energy use seems to be an important instrument for development and social change. Whilst low energy consumption is not the only cause of poverty and under-development, it does appear to be a close proxy for many of its causes. For example, environmental degradation, poor health care, inadequate water supplies and female and child hardship are often related to low energy consumption. As an example of this, Figure 1.6 shows life expectancy in 70 developing countries as a function of commercial energy use per capita per year (World Bank, 2000a)[5].

Figure 1.6: Life expectancy and energy use per capita



Empirically it appears that social conditions improve considerably as energy consumption per capita increases. Whilst development is a complex process, it is a paradigm of development policy that without appropriate energy services there can be no true economic development. Energy services in suitable forms are essential ingredients for future growth and development. Even now, around 2 billion people have no access to electricity and rely on traditional fuels, such as dung, crop residues and woodfuel. Another 2 billion have per capita consumption that is barely one-fifth of the average consumer in OECD countries.

The majority of these people lacking access to modern energy services are in the rural areas of developing countries. Bilateral and multilateral development aid in support of national efforts have included a variety of rural energy programmes, including investment projects, training and capacity building, to try to improve the provision of energy services. These include a wide range of activities managed by UNDP, the World Bank, the European Union, FAO and other agencies, together with projects funded via the Global Environment Facility and by bilateral organizations.

[5] Life expectancy at birth uses data for 1997, and commercial energy use per capita per year uses data for 1996.

Box 1 gives examples of some multilateral programmes undertaken by various UN agencies[6], (derived from UNDP/EC, 1999).

Box 1: Examples of energy activities of some UN agencies

Food and Agriculture Organization

FAO assists countries to meet their energy requirements in agriculture, forestry and fisheries as a means of achieving sustainable development. An integrated approach for the assessment, planning and implementation of energy and sustainable rural development is taken via technical assistance activities. The dual role of agriculture as a user and supplier of energy is a major factor in this work. Renewable energy applications are promoted especially in relation to enhanced agricultural productivity and other income generating activities. Networking is promoted, such as the Latin American and Caribbean Working group on Rural Energization for Sustainable Development, the Regional Wood Energy Development Programme in Asia and the Sustainable Rural Environment and Energy Network for the whole European Region.

Bioenergy data and projections are an important component of FAO's energy activities. Attention is also placed on the energy function of the sugar industry, as one of the diversification strategies of that sector, and to the production of low cost transport fuels to contribute to urban food security. FAO has also promoted awareness and better use of work animal technology.

Global Environment Facility

The GEF is an international financing mechanism that provides incremental funding for projects with global environmental benefits. It is also a funding mechanism for the UN Framework Convention on Climate Change and is jointly implemented by UNDP, UNEP and the World Bank. Medium-sized projects up to US$1M, project development activities and enabling activities can be funded via the GEF, and around 40% of funds allocated to date have supported climate change activities comprising energy efficiency and renewable energy projects, assessment and studies.

United Nations Development Programme

UNDP manages several energy-related programmes. Examples of two of these are:

- The Initiative for Sustainable Energy (UNISE) is a shift from the traditional supply-side approach, and links energy with social and environmental issues as well as with economic development. Activities are supported through global, regional and national programmes, including technical expertise and training;
- The FINESSE programme (Financing Energy Services for Small-scale Energy-users) aims to accelerate the commercialization of renewable energy technologies through pre-investment activities and the creation of the conditions and mechanisms for the credit sector to on-lend to small-scale energy users. FINESSE secures the involvement of small-scale operators, supporting franchise operations and enabling the local manufacture of key

[6] Visit <http://www.un.org/esa/sustdev/iaenr matrix.pdf> for the latest information on the energy activities of UN agencies.

components. In Southern Africa, the programme has funded market studies and business plans for investments in projects in biogas, PV, mini-hydro, and solar water heaters. A loan guarantee fund has been supplied to help business plans meet loan conditions.

United Nations Environment Programme

UNEP aims to stimulate cooperation action to respond to emerging environmental challenges and to promote greater awareness and facilitate effective cooperation among all sectors of society and the actors involved in the implementation of the international environmental agenda. The UNEP Energy Policy and Programme focuses on the need for a global shift to less carbon intensive energy systems and through this reduced adverse environmental impacts on local as well as on global levels by promoting:

- greater deployment of renewable and non-carbon energy technologies;
- efficiency improvements in conventional energy supply and end-use technologies;
- provision of better energy services from existing energy systems.

World Bank

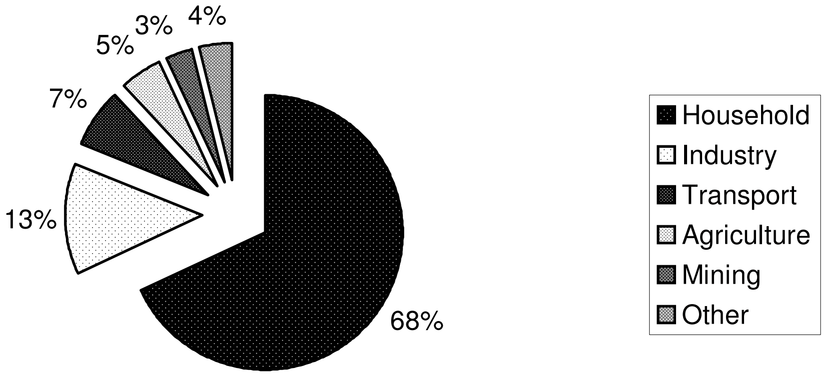
The World Bank ESMAP programme (Energy Sector Management and Assistance Programme) provides global technical assistance for the energy sector, including national energy assessments for over 60 countries that have helped pave the way for subsequent capital investment. The Bank has also launched a number of initiatives to encourage private sector investment in renewable energy in developing countries:

♦ The Renewable Energy and Energy Efficiency Fund (REEF), which finances private sector renewable projects of less than 50MW together with energy efficiency activities;
♦ The Solar Development Corporation (SDC), which is a collaboration with a number of foundations, and promotes stand-alone PV systems through private sector mechanisms;
♦ The PV Market Transformation Initiative (PVMTI) is a strategic intervention to accelerate the sustainable commercialization and financial viability of PV technology. PVMTI will make selected concessional investments in private sector PV market development projects in India, Kenya, and Morocco. With technical assistance and appropriately structured financing, these projects are eventually expected to provide successful examples of sustainable and replicable business models that can be financed on a commercial basis.

1.4 Energy Consumption by End-use Sector

Data on energy consumption by end-use sector in developing countries can be used to illustrate further the demand patterns for energy. As an example, Figure 1.7 shows the distribution of primary energy consumption by end-use sector in 10 southern African countries (FAO, 1995). The importance of energy in household use is clear from these data, with 68% of total energy consumption. Industry, transport and agriculture are all relatively small users. This picture is similar in many other developing countries, and contrasts with industrialized countries, where average household energy demand is around 40% of total energy use, and industry and transport are around 30% each.

Figure 1.7: Energy consumption in 10 southern African countries (1990)



1.5 Global Issues in Energy Supply and Demand

Changes in the way that energy is delivered to final consumers are taking place around the world. Energy generation, distribution and supply are moving from the public to the private sectors, and governments are now less likely to be directly involved in managing the energy business. Competition between private utilities is becoming more common, with the government role reducing to one of policy, oversight and regulation. There is also a move away from centrally planned generation and supply, with the market determining operational decisions and the allocation of investment funds. These trends are likely to continue, and are affecting developing and industrialized countries alike, with implications for investment in central power generating capacity and grid extensions.

Projections suggest that energy demand in developing countries will eventually overtake that of industrialized countries. Some forecasts are that on current trends world energy use will grow at 1.4% annually until 2020, with growth in OECD countries of 0.7% and growth in developing countries of 2.6% (WEC, 1995). According to this scenario, developing countries will reach the level of total consumption in OECD countries by 2015, as shown in Figure 1.8[7], and by 2050, they will have doubled it (WEC, 1995, and World Bank, 1999). Nevertheless, the level of energy consumption per head of population in developing countries will still be only one quarter of that in OECD countries.

Recent assessments from the World Energy Council (WEC, 2000a) have suggested that there are no technological or economic reasons why the world cannot enjoy the benefits of both a high level of energy services and a better environment. One consequence of this is that there is an opportunity for the development of energy services to follow a new path so that developing countries do not repeat the energy demand patterns of industrialized countries. However, a sustainable energy future will require economic, regulatory and institutional frameworks that facilitate appropriate investments, together with proper accounting for social and environmental externalities.

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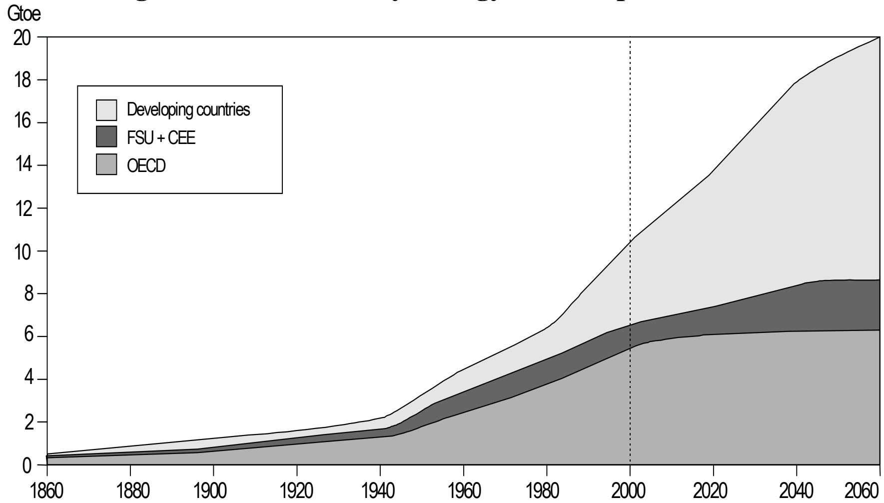
[7] The graph for the period 2000–2060 shows a scenario of future energy consumption based on current trends, and is intended as one illustration among many of recent energy demand projections.

Figure 1.8: Primary Energy Consumption Forecast



Some analysts suggest that the resource base for fossil fuels appears sufficient for there to be less concern than in the 1970s and 1980s about major supply shortages. Resources of both conventional and unconventional oil and gas are thought to be available for another 50-100 years with known technology and at current costs. Coal resources are abundant and should last for more than 100 years. As a result, these analysts affirm that petro-chemicals will remain commercially relevant well into the foreseeable future. However, other analysts observe that oil and gas resources are finite, and that use of these resources are likely to become increasingly reserved for higher value petro-chemical production rather than for fuel supply. This view suggests that the longer-term uncertainties regarding energy supply, together with the forecasts of considerably increased energy demand during the next 50-60 years could produce energy market difficulties in future years. There are also views that suggest that a transition to renewable energy will precede any eventual fossil fuel depletion because of environmental concerns.

Nevertheless, the focus of attention in energy policy is currently being placed on the efficiency by which fossil fuel energy resources are utilized, improving the regulatory and investment framework in which energy is supplied to end-users and tackling the environmental impacts of energy technologies, including their role in climate change. These tend to be the shorter to medium term priorities in energy policy formulation.

1.6 Local Environmental Impacts

The combustion of fossil fuels and traditional woodfuels can create adverse local environmental effects. In developing countries, the local environmental problems associated with energy use remain matters of concern that are as, or even more, urgent than they were in industrialized countries 50 or 100 years ago. Further, it is the poor who suffer most from such problems, because it is they who are forced to rely upon the most inefficient and polluting sources of energy services for lack of access to better alternatives. The connection between woodfuel use, cooking and the epidemiology of respiratory and other illnesses is a topic of active research. Nevertheless, a consistent pattern linking energy, environment and health has become clear (World Bank, 1999). Woodfuel combustion in confined, often unventilated indoor areas and at low thermodynamic efficiency leads to high concentrations of smoke and other pollutants.

The World Bank has estimated that the economic costs of air pollution from all sources are US$ 350B/year, or the equivalent 6% of GNP of all developing countries. Much attention is now being given to technical and policy measures that can reduce the local environmental impact of energy use.

1.7 Climate Change

An issue of much relevance to future energy policy is mitigation of the effects of global climate change. Industrialized countries are responsible for at least 80% of the build-up of greenhouse gases in the atmosphere, and consumption of fossil-fuel derived energy accounts for the largest share of anthropogenic emissions of greenhouse gases. Through the UN Framework Convention on Climate Change and Agenda 21 (UNCED, 1992), the international community has agreed to work together to meet the problems of climate change, and industrialized countries are taking steps to reduce or stabilize their emissions of CO_2 and other greenhouse gases.

The implementation of the Kyoto Protocol, once in force, or of any other agreement, which might develop from the Protocol, will greatly influence energy policy, investment decisions and the development and deployment of energy technologies. The Protocol assigns legally binding emission reduction targets and through Joint Implementation and the Clean Development Mechanism, industrialized countries (listed in Annex 1 to the Protocol) can meet part of these targets by financing initiatives to reduce greenhouse gas emissions in other countries. This process may help to lever new financial support for sustainable energy development projects by providing additional benefits to investors (UNDP, 1998). Dealing with climate change will require global efforts to control greenhouse gas emissions. Emissions from developing countries are increasing, and will eventually naturally exceed those of industrialized countries. The means by which economic growth and increased energy demand can be reconciled with protection of the local and global environment is central for future sustainable energy development.

1.8 Energy Security, Diversity of Supply and the Role of Renewable Energy

In simple terms, the concept of diversity of supply means not placing too much reliance on any single fuel, technology or other factor. Ensuring that there is diversity of fuel supply has long been a central theme within energy policy - both for primary fuel supplies and for sources of supply for derived electricity. Diversity has been of particular importance at times of oil price volatility and as one theme of the nuclear energy debate. One way of considering the benefits of diversity is to assess the variety, balance and disparity of fuel supply.

Variety of fuel supply considers the number of options available, including different technologies as well as fuel sources; the balance of supply must take into account how much the mix relies on any one of the available options while any disparity of supply assesses any qualitative differences between them. The central concept of diversity is responding to uncertainty and this underpins energy security - in turn this helps deliver economic performance and improves quality of life. Any failure to supply energy results in lost output and costs to industry, commerce and domestic users.

Diversity should, therefore, be seen as a means of providing greater strength in guarding against unforeseen events. It offers a kind of risk management which reduces the potential adverse impacts resulting from interruptions in supply, or excessive price rises in any single supply sector. It also provides additional options for substitution or replacement of supplies on which a country or region has become over-reliant. Diversity confers some insurance in the face of ignorance about the short and long term availability or price of any single energy source.

Indeed, history has shown that supply 'shocks' and extreme price volatility can have major economic and social impacts through national economies. The effects seem to be particularly sensitive when there is undue reliance on imported fuel oils. The oil price rises in 1973-74 led to major government initiatives in renewable energy, energy efficiency (conservation) and nuclear power development with a view to mitigating the risk associated with heavy use of oil. As we enter the 21st century, although fossil fuel reserves seem sufficient, global concerns for the environmental implications of fossil-fuels for electricity and heat generation and their use in transport have changed perceptions about choices of fuels and opened a wider debate about the most appropriate global energy development pathway.

Following the "oil crises" and rapid oil price rises of the early 1970s, diversity of supply arguments stimulated the first wave of development of new and renewable energy systems in the mid-1970s. Low oil prices in the 1980s tended to reduce the thrust of this effort, but interest in renewable energy has been revived during the 1990s, and looks set to continue into the 21st century. Renewable energy sources have the potential to meet an increasing proportion of the world's energy needs over the coming decades. The basic reason for this is that modern renewable energy systems can make positive contributions against a number of underlying economic and social drivers - the drivers that determine the development and deployment of new energy technologies.

Hence, renewable energy systems are seen to offer benefits in terms of reducing the local environmental impact of energy production; they can provide both employment opportunities and economic benefits in rural areas due to their inherent localised nature. Renewable energy sources are an important means of providing increased diversity and security of supply, and they also offer another set of energy supply options that can mitigate the impact of climate change by substituting for fossil fuels. Overall, therefore, an increasing role for renewable energy is considered important to achieve a more sustainable energy future in both industrialized and developing countries alike.

1.9 Renewable Energy Technologies

Most renewable energy sources have low environmental impacts at both local and global levels compared with conventional fossil fuel energy technologies; they are available in a wide range of capacities; they offer fuel diversity and can make use of local resources to deliver energy to local users without extensive infrastructure investments. The technical potential for renewable energy in both industrialized and developing countries is very large. Table 1.1 lists the results of some recent modelling studies on the potential global market for renewable energy (DTI, 1999). Whilst these studies are very much "top-down" assessments of the broad potential for renewable energy systems, and do not take account of issues such as local conditions, and the influences of energy markets, a significant expansion of renewable energy systems in all scenarios studied is indicated.

Table 1.1: Summary of modelling studies for renewable energy markets

Study	Time Horizon	Potential renewable energy contribution
IEA	2010	4%of electricity, 2% of total energy (excluding 'non commercial use', estimated at 15-20% of total energy)
World Energy Council	2050	Up to a 25% share of global markets (from the current level of around 18%)
UN	2050	Current contribution of 20% will rise to 60% of electricity and 40% of other fuels
Shell International	2060	Up to 40% of total energy supply

The high long-term market penetration levels predicted by these studies are associated with substantial levels of capital investment in plant and equipment, and yet despite considerable research and development, the exploitation of modern renewable energy sources is still in its infancy. A prime reason is their lack of cost-effectiveness, together with the availability and reliability of the current renewable energy technologies. Furthermore, certain renewable systems are able to provide power only intermittently, and may need storage via batteries to give greater availability. It is worth noting that biomass technologies are an exception to this rule, as they utilize a resource that can be stored for use on demand when required, and which is not directly subject to short-term variations in weather (such as rainfall, wind or sunshine).

Bringing renewable energy systems to technical maturity will require substantial cost reductions, and continued efforts will be needed in demonstrating their contribution in competition with conventional fuels. A transition to a renewable based system will depend on political willingness to internalize the environmental and social costs of fossil fuel use, and on the successful development and deployment of technologies in appropriate commercially viable applications. Financial, administrative and institutional entities will also have to adapt their policies to take account of renewable energy systems so that barriers to market entry can be minimized.

1.10 The Energy Challenge

The current patterns of energy production and use, which have shaped the development process in the past, are unsustainable. The energy challenge now faced by countries around the world is to provide energy services that allow all people to achieve a decent standard of living, consistent with sustainable human development. This link between energy and development remains a key factor in development policy. It will be shaped by current trends of globalization, markets and popular participation in decision-making processes, the changing roles of government and energy utilities, and the mix of sources of external funding.

The World Energy Council has suggested (WEC, 2000b) that addressing the three goals of energy accessibility, availability and acceptability is fundamental to political stability world-wide, to stimulating new energy business strategies for the new century and to achieving a sustainable future for the world. Following the work done in establishing Agenda 21, UNDP has also identified (UNDP, 1997, and UNDP/EC, 1999) the need for a focused examination of the role of energy in achieving sustainable socio-economic development and has identified a series of actions required to increase the adoption of sustainable energy options. More recently, the World Bank has proposed a greater focus on rural energy in its lending for the energy sector, and is planning to bring renewable energy considerations more prominently into non-power sector lending, such as in the agriculture sector (World Bank, 1999).

FAO has had significant experience with the energy needs of the agricultural sector. Bioenergy issues and biofuels have been on the organization's agenda for decades. Over the last 10-15 years FAO has supported many rural energy projects in developing countries. These activities aim to assist developing countries to meet their energy requirements in agriculture, forestry and fisheries as a means of achieving sustainable development. A transition from the present energy supply of mainly woodfuel and animal and human work, to a more diversified base and a better use of modern energy technologies, is seen as key to improving the living conditions of rural populations (WEC/FAO, 1999).

Agriculture is an important, but not dominant, user of energy in developing countries. Nevertheless, improving energy services for rural people should include increasing the energy input to agriculture so that gains in productivity, enhanced food security and rural economic development can be made. Even a small amount of additional energy, normally insignificant at the level of national energy balances, can make an important contribution to a local rural economy. Due to its capacity for production of biomass, agriculture is also a potential source of renewable energy supply. Recognizing the dual role of agriculture as the first step in mobilizing its energy function is the main theme of this report. Together with the challenges faced by the international community in responding to the local and global environmental impacts of energy use, there is now a major opportunity for agriculture to play an important extra role in sustainable energy development.

Chapter 2: Energy for Agriculture

2.1 Entry Levels for Interventions

This Chapter looks specifically at the agricultural sector and its energy inputs. It is useful to consider three entry levels for interventions as a means of examining both the energy needs for agriculture and the requirements for rural energy services in developing countries. These three levels are based on the "energy ladder" approach. For agriculture, the three-stage evolution can be considered as follows:

- basic human work for tilling, harvesting and processing, together with rain-fed irrigation, none of which involve an input from an external fuel source;
- then the use of animal work to provide various energy inputs;
- finally, the application of renewable energy technologies such as wind pumps, solar dryers and water wheels, together with modern renewable and fossil fuel based technologies for motive and stationary power applications, and for processing agricultural products.

For rural energy, the needs of poor people can be considered at the following three levels:

- energy for basic survival in cooking, lighting and space heating using traditional biomass fuels;
- then as people move up from subsistence, alternatives to traditional biomass fuels in these applications such as kerosene and LPG;
- finally, the role of enhanced energy services in rural areas using modern renewable energy and fossil fuels, for example in providing energy for small electrical appliances (e.g. lighting and radio) and the provision of community facilities (e.g. street lighting, water pumping, power for health centres and schools).

In both household and economic activities, the "energy ladder" follows and influences the "economic ladder". Attempts to alleviate poverty and to promote rural economic development and food security must be accompanied with efforts to promote the key role of energy, not simply as a goal in itself but as a vital component of these attempts.

Table 2.1 lists items in the conceptual framework relating the level of household income and the types or sources of energy services adopted by rural populations (DFID, 1999). The framework includes household, agriculture, small-scale rural industry and transport end-use requirements, and is based on empirical evidence. It illustrates the progression to modern fuels as income rises, and is based on empirical evidence gathered by the World Bank and other agencies. The data show that rural people choose to spend a significant proportion of their incomes on a better source of energy if they have access (World Bank, 1995). The table shows how opportunities generally increase and the efficiency of energy utilization also increases, while the negative impacts of energy use decrease with rising household incomes.

It can be seen that woodfuel still plays an important role for households even at higher income levels. In agriculture and industry, diesel engines and electricity replace human and animal work; where rural electrification is not available or is too costly, diesel generators may be used instead. Wind pumping for water extraction from wells, together with mini-hydro and, more recently, PV systems for small-scale electricity supplies for homes, farms and community buildings are possible renewable energy options. The use of these options may appear in future empirical evidence.

Table 2.1: Levels of household income and energy services

End use	Household income		
	Low	Medium	High
Household			
Cooking	Wood, residues, dung	Wood, charcoal, dung, kerosene, biogas	Wood, charcoal, coal, kerosene, biogas, LPG, electricity
Lighting	Candles and kerosene	Candles, kerosene, gasoline	Kerosene, electricity, gasoline
Space heating	Wood, residues, dung	Wood, charcoal, dung	Wood, charcoal, dung, coal
Other appliances	Batteries (if any)	Electricity, batteries	Electricity, batteries
Agriculture			
Tilling	Human	Animal	Animal, gasoline, diesel
Irrigation	Human	Animal, wind pumps	Diesel, electricity
Post-harvest processing	Human, sun drying	Animal, water mills, sun drying	Diesel, electricity, solar drying
Rural Industry			
Mechanical tools	Human	Human, animal	Human, animal, diesel, electricity
Process heat	Wood, residues	Coal, charcoal, wood, residues	Coal, charcoal, wood, kerosene, residues
Transport			
Motive power	Human	Human, animal	Human, animal, diesel, gasoline

2.2 Energy and Agricultural Production

Agriculture is itself an energy conversion process, namely the conversion of solar energy through photosynthesis to food energy for humans and feed for animals. Primitive agriculture involved little more than scattering seeds on the land and accepting the scanty yields that resulted. Modern agriculture requires an energy input at all stages of agricultural production such as direct use of energy in farm machinery, water management, irrigation, cultivation and harvesting. Post-harvest energy use includes energy for food processing, storage and in transport to markets. In addition, there are many indirect or sequestered energy inputs used in agriculture in the form of mineral fertilizers and chemical pesticides, insecticides and herbicides.

Whilst industrialized countries have benefited from these advances in energy availability for agriculture, developing countries have not been so fortunate. "Energizing" the food production chain has been an essential feature of agricultural development throughout recent history and is a prime factor in helping to achieve food security. Developing countries have lagged behind industrialized countries in modernizing their energy inputs to agriculture.

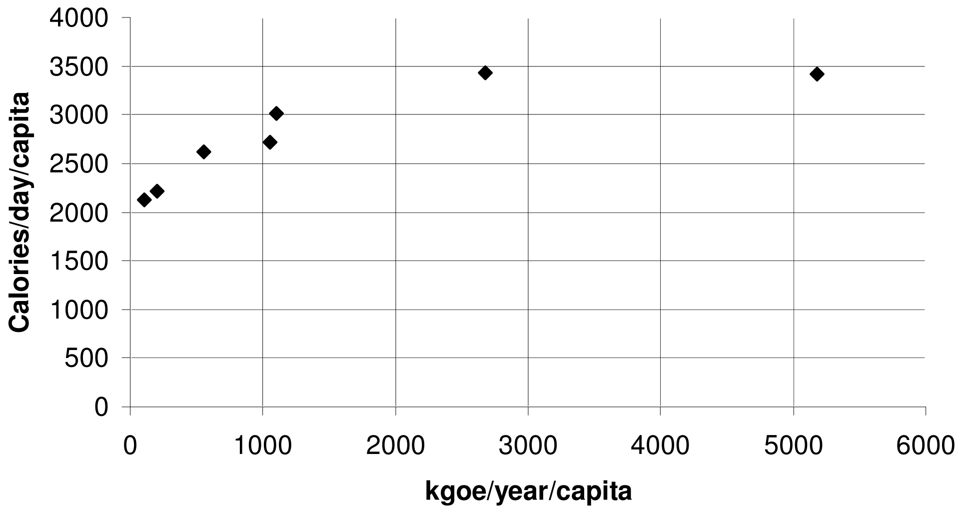
As indicated in Chapter 1, agriculture accounts for only a relatively small proportion of total final energy demand in both industrialized and developing countries[8]. In OECD countries, for example, around 3-5% of total final energy consumption is used directly in the agriculture sector. In developing countries, estimates are more difficult to find, but the equivalent figure is likely to be similar - a range of 4-8% of total final commercial energy use.

The data for energy use in agriculture also exclude the energy required for food processing and transport by agro-industries. Estimates of these activities range up to twice the energy reported solely in agriculture. Definitive data do not exist for many of these stages, and this is a particular problem in analysing developing country energy statistics. In addition, the data conceal how effective these energy inputs are in improving agricultural productivity. It is the relationships between the amounts and quality of the direct energy inputs to agriculture and the resulting productive output that are of most interest.

2.3 Commercial Energy Use and Agricultural Output

On a broad regional basis, there appears to be a correlation between high per capita modern energy consumption and food production. Figure 2.1 shows data for daily food intake per capita and the annual commercial energy consumption per capita in seven world regions (FAO, 1995)[9].

Figure 2.1: Modern energy consumption and food intake



Whilst broad data on a regional basis conceal many differences between countries, crop types and urban and rural areas, the correlation is strong in developing countries, where higher inputs of modern energy can be assumed to have a positive impact on agricultural output and food production levels. The correlation is less strong in industrialized regions where food production is near or above required levels and changes in production levels may reflect changes in diet and food fashion rather than any advantages gained from an increased supply of modern energy.

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[8] Methodological limitations regarding the boundaries of data collection, statistical analysis and definitions may mask the true picture. However, the basic assessments and propositions in this Chapter remain valid.

[9] The regions are (in ascending order of energy use per capita): Sub-Saharan Africa, South Asia, East Asia/Pacific, Latin America/Caribbean, Middle East/North Africa, Europe, OECD.

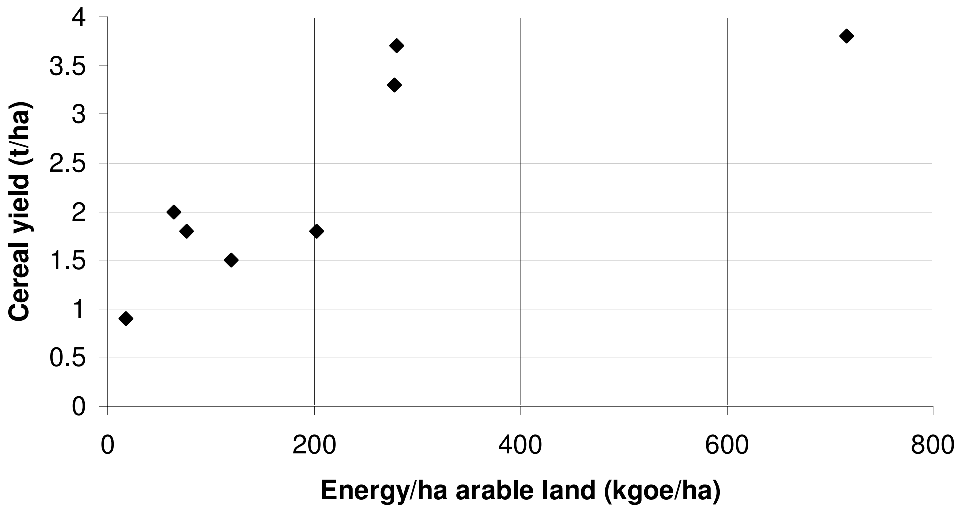
Looking more closely at energy use in specific crops, comparisons of commercial energy use in agriculture for cereal production in different regions of the world are listed in Table 2.2 (Stout, 1990). The relationship between commercial energy input and cereal output per hectare for the main world regions is also shown in Figure 2.2 (Stout, 1990). These data, whilst relatively old, indicate that developing countries use less than half the energy input (whether in terms of energy per hectare of arable land or energy per tonne of cereal) compared with industrialized countries. However, this is not to say that developing countries are necessarily more efficient in their use of energy for agricultural production. **This energy statistic does not account for the quantity of human effort used in developing countries for agriculture. In drawing conclusions, it is also important to consider the equity and sustainability considerations when comparing energy use data.**

Empirical evidence suggests that the availability of modern energy such as petroleum fuels has proven to be essential in increasing the productivity of the agricultural sector in industrialized countries. In terms of the energy used per agricultural worker, the differences are even more dramatic, with developing countries using less than 5% of the energy per agricultural worker compared with industrialized countries. An obvious difference between industrialized and developing countries is the large numbers of agricultural workers per hectare in developing countries compared with industrialized countries.

Table 2.2: Commercial energy use and cereal output (1982)

Region	**Energy per hectare of arable land (kgoe/ha)**	**Energy per tonne of cereal (kgoe/t)**	**Energy per agricultural worker (kgoe/person)**
Africa	18	20	26
Latin America	64	32	286
Far East	77	43	72
Near East	120	80	285
All developing countries average	96	48	99
All industrialized countries average	312	116	3294
World average	**195**	**85**	**344**

Figure 2.2: Cereal yield and energy input per hectare for the main world regions[10]



In general, those regions with higher energy consumption have higher agricultural yields. However, the relationships between energy input and agricultural output are also affected by the varying ecological and environmental conditions around the world; soil fertility and rain-fed water availability being prime examples. Exact comparisons at the national level are, therefore, not easily made, but it is possible to use energy inputs for specific crops to gain further insights into the relationship between energy use and agricultural productivity.

As an example of this, a comparison between the commercial energy required for rice and maize production by modern methods in the United States, and transitional and traditional methods used in the Philippines and in Mexico is shown in Table 2.3. These data show that the modern methods give greater productive yields and are much more energy-intensive than transitional and traditional methods (Stout, 1990). These methods include the use of fertilizer and other chemical inputs, more extensive irrigation and mechanized equipment.

Table 2.3: Rice and maize production by modern, transitional and traditional methods

	Rice production			Maize production	
	Modern (United States)	Transitional (Philippines)	Traditional (Philippines)	Modern (United States)	Traditional (Mexico)
Energy input (MJ/ha)	64,885	6,386	170	30.034	170
Productive yield (kg/ha)	5,800	2,700	1,250	5,083	950
Energy input yield (MJ/kg)	11.19	2.37	0.14	5.91	0.18

A further illustration of the relationship between energy intensity and agricultural productivity is given in Box 2. This presents a case study of energy use in durum wheat production in

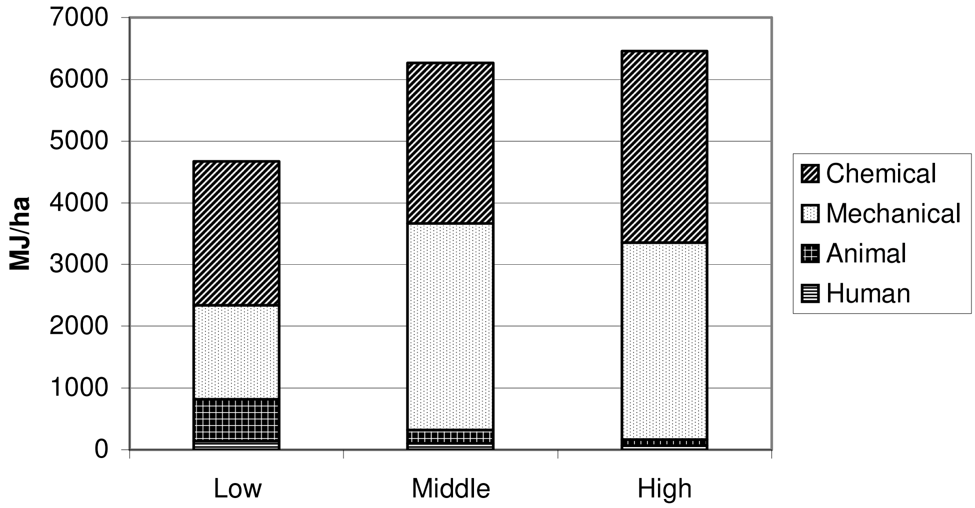
[10] The world regions used (in ascending order of energy per hectare of arable land) are: Africa, Latin America, Far East, Near East, Eastern Europe, Asia, North America, Western Europe.

Tunisia (Myers, 1983). The study showed that farms with the highest energy input per hectare had the highest production and lowest input per tonne of production.

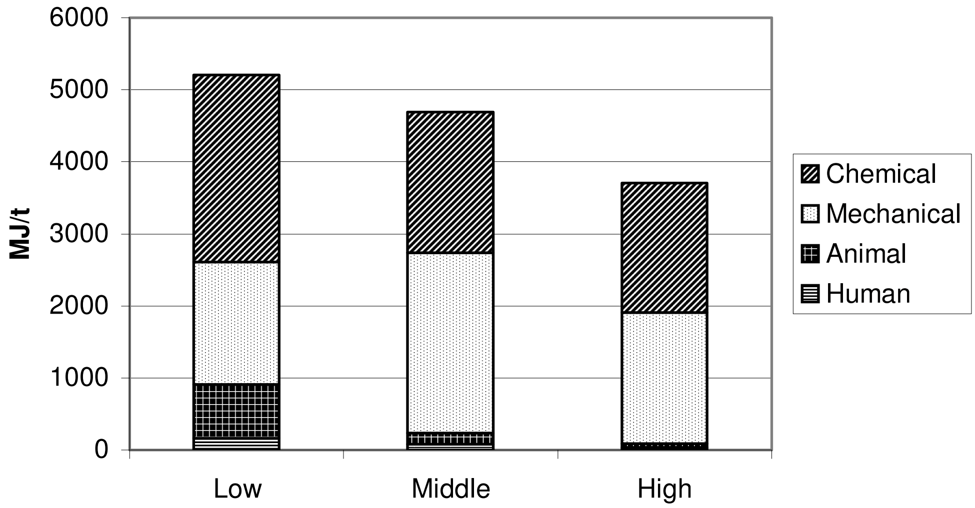
Box 2: Energy Use in Durum Wheat Production in Tunisia

Data from 23 small and medium-sized farms in northern Tunisia were collected in 1983. This region contains the most fertile land in Tunisia and has fairly stable production patterns. The farms were divided into three yield classifications: low (600-1000 kg/ha); middle (1010-1500 kg/ha) and high (1510-2500 kg/ha). Total energy use per hectare was found to increase and total energy use per tonne decreased as the yield increased. Farms with the highest energy input per hectare had the highest production and lowest energy input per tonne of production. Overall energy use per hectare also increased as the yield increased, whilst both human and animal work decreased. However, the use of chemical energy inputs (fertilizer and pesticide) increased as the yield increased.

Energy use per hectare for three yield classifications:



Energy use per tonne for three yield classifications:



2.4 Agricultural Energy Needs

Agriculture practices in many developing countries continue to be based to a large extent on animal and human energy. Insufficient mechanical and electrical energy is available for agriculture, and hence the potential gains in agricultural productivity through the deployment of modern energy services are not being realized. Agricultural energy demand can be divided into direct and indirect energy needs. The direct energy needs include energy required for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage and the transport of agricultural inputs and outputs. Indirect energy needs are in the form of sequestered energy in fertilizers, herbicides, pesticides, and insecticides.

Mankind has adapted a variety of resources to provide for energy in agriculture. Animal draught power obtained through domestication of cattle, horses and other animals has existed for over 8,000 years, the water wheel is over 2,000 years old, and windmills were introduced over 1,000 years ago. Direct sun energy for drying and biomass fuels for heating have also been prominent as agricultural energy inputs for centuries.

The bulk of direct energy inputs in developing countries, particularly in the subsistence agriculture sector, is in the form of human and animal work. **Human work has a limited output, but humans are versatile, dextrous and can make judgements as they work.** This gives humans an advantage in skilled operations such as transplanting, weeding, harvesting of fruits and vegetables and working with fibres. Water lifting and soil preparation need less skill but more energy input. A sustainable rate at which a fit person can use up energy is around 250-300 W, depending on climate and needing 10-30 minutes/hour rest. The efficiency of energy conversion is only about 25%, with a maximum sustainable power output of 75 W. Table 2.4 lists human power consumption for various farming activities (Carruthers and Rodriquez, 1992).

Table 2.4: Human power consumption for various farming activities

Activity	Gross power consumed (W)
Clearing bush and scrub/felling trees	400-600
Hoeing, planting	200-500
Ridging, deep digging	400-1000
Ploughing with draught animal	350-550
Driving 4 wheel tractor	150-300
Driving single axle tractor	350-650

Animals provide transport of products, can pull implements and lift water and are used in processing activities such as cane crushing and threshing. The world population of draught animals is estimated at over 400 million (WEC/FAO, 1999). Animal work can alleviate human drudgery and increase agricultural production. Power output ranges from 200 W for a donkey to over 500 W for a buffalo, and daily working hours range from 4 hours for a donkey up to 10 hours for a horse. There are limitations on the performance of animals, especially at times when they are needed most in the dry season with feed, grazing and water in short supply. Implements used by animals can be pole-pull, chain-pull or wheeled carriers. Table 2.5 lists power and energy characteristics of typical farm animals in good condition (Carruthers and Rodriquez, 1992).

Table 2.5: Power and energy output of individual farm animals

Animal	Typical weight (kN)	Pull-weight ratio	Power output (W)	Energy output per day (MJ)
Ox	4.5	0.11	450	10
Buffalo	5.5	0.12	520	9.5
Horse	4.0	0.13	500	18
Donkey	1.5	0.13	200	3
Mule	3.0	0.13	400	8.5
Camel	5.0	0.13	650	14

It seems likely that both human and animal work will continue to be used as agricultural inputs for the foreseeable future in developing countries. Efforts to support these farming traditions include work on animal efficiency, which can be improved through modernization of equipment, better breeding and animal husbandry, feeding and veterinary care, and on improved designs of animal-drawn farm equipment.

2.5 Mechanization and Conservation Agriculture

A transition to increased mechanization of farm operations has been undertaken over a long period of time. Table 2.6 lists selected indicators of agricultural mechanization using tractors and harvesters for different world regions expressed in terms of cropland area and numbers of agricultural workers (WRI, 1994). The data show a wide disparity in the degree of mechanization between the different regions, with Africa having the lowest level of mechanization.

Table 2.6: Selected indicators of agricultural mechanization

	Africa	Latin America	Europe	World
Total population 1990 (million)	643	294	509	5,295
1990 agricultural workforce (million)	211	40	30	1481
Cropland (million ha)	181	115	138	1,441
Tractors	544,000	1,125,000	10,384,000	26,411,000
Agricultural workers/tractor	387	36	3	56
Hectares/tractor	333	102	13	55
Harvesters	70,000	117,000	831,000	3,956,000
Agricultural workers/harvester	3,019	340	36	374
Hectares/harvester	2,599	980	166	364

Tillage operations are used within arable farming systems, which are often the operations with the highest energy requirements. Mechanized soil tillage has in the past been associated with increased soil fertility, due to the mineralization of soil nutrients; it also allows higher working depths and speeds and the use of implements such as ploughs, disc harrows and rotary cultivators. This process leads in the long term to a reduction of soil organic matter, and most soils degrade under long lasting intensive arable agriculture with particularly detrimental effects on soil structure. The process is dramatic under tropical climate conditions but can be noticed all over the world. Reduction of mechanical tillage and promotion of soil organic matter through permanent soil cover is an approach to reverting soil degradation and other environmental impacts of conventional agriculture, achieving at the same time a high agricultural production level on truly sustainable basis. This approach is described as 'conservation agriculture' and replaces mechanical soil tillage by 'biological tillage'.

In this approach, crop residues remaining on the soil surface produce a layer of mulch which protects the soil from the physical impact of rain and wind, and also stabilizes the soil surface layers moisture content and temperature. This zone becomes a habitat for a number of organisms which macerate the mulch, mix it with soil and assist its decomposition to humus. Agriculture with reduced mechanical tillage is only possible when soil organisms take over the task of tilling the soil. This leads to other implications regarding the use of chemical inputs since synthetic pesticides and mineral fertilizers have to be used in a way that does not harm soil life. Conservation agriculture can only work if all agronomic factors are equally well managed[11].

It should also be noted that, whilst shifts from human work to mechanized processes may offer more efficient use of resources, and deliver productive and economic benefits, the agricultural sector does provide a source of paid employment for rural people in developing countries. A balance is often required between the socio-economic benefits and the agricultural productive benefits of changing the processes (and thereby the energy inputs) involved.

2.6 Chemical inputs

Fertilizers, and other chemical inputs to agriculture, have proved important in the past in increasing food production in all regions of the world. Mineral fertilizers, chemical pesticides, fungicides and herbicides all require energy in their production, distribution and transport processes. Fertilizers form the largest of these energy inputs to agriculture, whilst pesticides are the most energy-intensive agricultural input (on a per kg basis of chemical). The need for insecticides and fungicides can, however, be reduced through greater use of pest control methods based on the principals of integrated pest management.

The energy contents of various agricultural inputs[12] are listed in Table 2.7, which show illustrative values of the energy required for manufacturing these products. Full life-cycle values (i.e. from extracting the chemical raw material through to final delivery of the manufactured product to the field) would depend on several highly variable factors. These

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[11] Additional information about the work of FAO in conservation agriculture can be found at <http://www.fao.org/ag/ags/agse>.

[12] Source: Data derived from Stout, 1990, and FAO statistics estimates. Additional data may be found from the IFOAM web site <http://www.ifoam.org>.

include the actual location of chemical raw material supplies relative to the productive facility, the ease of extraction, the chemical manufacturing processes, and the distances involved in transporting raw, semi-finished and finished products.

Table 2.7: Energy content of agricultural inputs

Input		Typical rate of application (kg/ha)	Sequestered energy (MJ/kg)	Energy content of crop produce (MJ/ha)
Fertilizer	Nitrogen	150	65	9,750
	Phosphate	60	9	540
	Potash	60	6	360
Insecticide		0.14	200	28
Herbicide		5	240	1,200
Fungicide		3	92	276
Seed		120	14	1,680

By comparison with the energy content of mineral fertilizer, the energy content of fresh manure is much lower at around 0.35 MJ/kg. However, the amount of plant, human and animal wastes available in developing countries that could potentially be used for organic manure is several times the consumption of chemical fertilizers in these countries. The volume of fertilizer input to agriculture differs markedly between regions of the world, as shown in Table 2.8 (WRI, 1994). The data, which are broad regional estimates, show that Africa and Latin America use very low inputs compared with Asia and Europe.

Table 2.8: Fertilizer input to agriculture (1990)

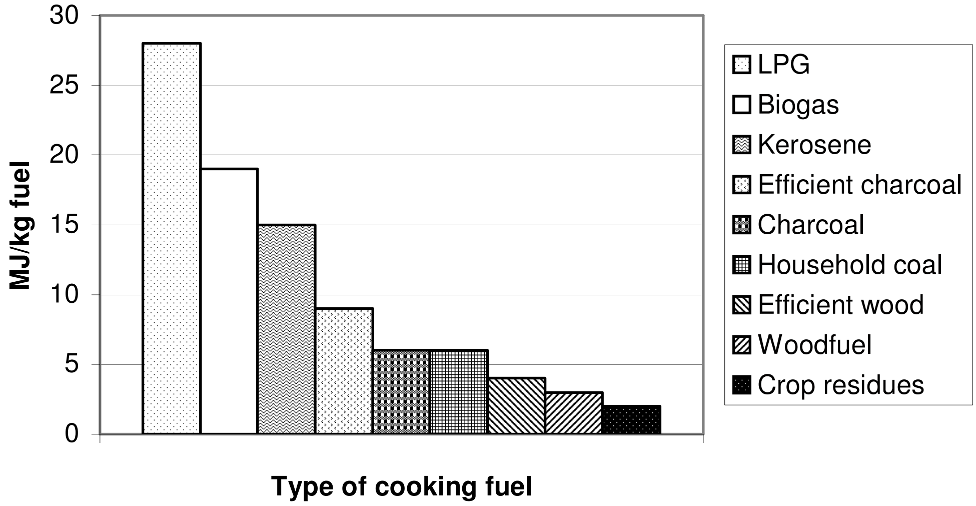
	Average annual fertilizer use (kg/ha crop land)
World	96
Africa	20
Asia	123
Europe	192
North and Central America	87
Latin America	44

Agricultural practices are, however, changing throughout the world. In recent years, diminishing returns from increased use of fertilizers and pesticides have raised questions about their role in the transition towards more environmentally-sound agricultural practices. The main constraints in increasing organic manure use are the large labour and skills content required together with the need to change cultural attitudes and the lack of mixed livestock and crop husbandry.

2.7 Cooking

Energy is required for cooking most foods, and for boiling water for drinking, washing and for partial water purification. In small-scale food cooking, many rural households continue to rely on woodfuel. Figure 2.3 presents data on the efficiency of various cooking fuels (World Bank, 1995). The data are derived from a combination of the energy content of each fuel and the efficiency with which the fuels are typically burned for cooking in developing countries.

Figure 2.3: Energy efficiency of selected cooking fuels



Traditional biomass are generally much less efficient for cooking than modern, commercially traded fuels such as liquefied petroleum gas and kerosene. These fuels have higher energy values per unit of weight than woodfuels, and are generally used in more efficient stoves. In addition, the level of heat output of kerosene stoves can be adjusted, so making kerosene more convenient for preparing a wide range of foods. Another versatile fuel is biogas, derived from digesters using dung and farm residues, and both China and India have done much to develop biogas and encourage its use among people in rural areas. The least efficient fuels are agricultural residues, but poor people are forced to use these fuels where they are available in the local environment because they have no cash cost.

Improved cooking stove programmes have been a feature of many rural energy interventions over the last 20 years (FAO, 1996a). Work has been carried out on establishing multi-sectoral support and involvement, and integrating technology, dissemination and financing. National standards on cooking and heating efficiency and guidelines for stove programmes have been developed. Studies have shown that the health and quality of life of both women and children can be improved by improving access to biomass and providing biomass stoves which are designed to be safer to use in terms of reduced risk of burns, respiratory disease and eye problems (World Bank, 1995). Indeed, the thrust of the current work on improved cooking stoves has become one of reducing the adverse health impact of traditional cooking methods rather than one of achieving potential fuel savings or increasing stove energy efficiency.

2.8 Energy and Agroprocessing

The agroprocessing industry transforms products originating from agriculture into both food and non-food commodities. Processes range from simple preservation (such as sun drying) and operations closely related to harvesting, to the production, by modern, capital-intensive methods of such articles as textiles, pulp and paper. Upstream industries are engaged in the initial processing of products, with examples such as rice and flour milling, leather tanning, cotton ginning, oil pressing, saw milling and fish canning. Downstream industries undertake further manufacturing operations on intermediate products made from agricultural materials.

Examples are bread and noodle making, textile spinning and weaving, paper production, clothing and footwear manufacture and rubber manufacture[13].

An energy input is required in food processing, as well as in packaging, distribution and storage. Many food crops when harvested cannot be consumed directly, but must pass through several stages of processing as well as cooking in order to be palatable and digestible. Raw meats, uncooked grains, vegetables and even fruits require preparation and heating to enhance their flavour, rendering their components edible and digestible. The processing and cooking stages reduce harmful organisms and parasites, which might pose health hazards.

Poorly handled and stored food can become spoiled and contaminated. Food preservation usually requires the application of heat to destroy micro-biological agents, such as bacteria, yeast and mould. Pasteurization causes the inactivation of spoilage enzymes and reduction of bacteria at temperatures around 80-90^{o}C. Heat sterilization can use atmospheric steam at 100^{o}C for high-acid foods, and pressurized steam at around 120^{o}C for low acid foods. Other techniques include dehydration to reduce moisture content, pickling/smoking to reduce microbial activity, fermentation, salting and freezing.

Food transformation activities are generally less energy-intensive and release less CO_2 and metal residues than most other industrial activities per unit of product. As described in more detail below, agroprocessing industries, such as sugar mills, can become not only energy self-sufficient through the energy conversion of biomass residues, but also electricity producers for export to other users.

2.9 Energy Policies in Agriculture

The international community has agreed that a priority in Agenda 21 should be promoting sustainable agriculture and rural development (SARD) and one of the programme areas [Chapter 14k in Agenda 21] is to encourage a rural energy transition in order to enhance productivity (UNCED, 1992). The objectives of this programme area include initiating the required transition by making available new and renewable sources of energy and increasing the energy inputs available for rural household and agro-industrial needs. Rural programmes favouring sustainable development of renewable energy sources and improved energy efficiency are also called for in Agenda 21 in the programme area dealing with protection of the atmosphere [Chapter 9b in Agenda 21].

CSD-8 in April 2000 included agriculture and forests as the major economic sector for discussion, and CSD-9 in April 2001 will examine atmosphere and energy as sectoral themes and energy and transport as economic themes. There are clear links between these two sessions of CSD.

The international framework for action does, therefore, exist. Nevertheless, it seems clear from the data presented in this Chapter that there is a wide disparity between energy inputs in agriculture in industrialized countries with that in developing countries and that this disparity is hindering agricultural productivity gains. One consequence of this is that enhanced food security is more difficult to achieve. This affects not only the quantity of food produced, but

[13] Further information on FAO's work in the agroprocessing industry and economic development can be found at http://www.fao.org/apps/advsearch/adv_search.asp.

also the quality - people are forced to eat uncooked food or food that can easily be cooked but which may not give full nourishment.

This situation is manifest in the general lack of an agricultural component in rural energy development policies. Agriculture contributes significantly to economic and social development, accounting for around 30% of developing country GDP[14], but energy provision for agriculture has not received the attention that the sector deserves. The World Bank has observed (World Bank, 2000b) that most energy policies in developing countries have traditionally focused on large capital investments in the generation and transmission of electricity, gas and petroleum products, so enabling the commercial development of energy supply industries. These policies are designed mainly for the needs of industry, transport and urban infrastructure, and thereby focus most attention on urban populations, whilst rural populations (and to some extent peri-urban populations) and their energy requirements are frequently overlooked.

Even where there has been a focus on rural energy and development and attention given to the scope for improving energy services to rural populations, much of the work has concentrated on the household use of energy. For example, there have been many programmes to expand the use of improved cooking stoves and to provide households and community buildings with small amounts of electrical power through the development of solar home systems using PV technology. Whilst these PV programmes offer many benefits at the household level, none of them have directly tackled the energy supply problems in the agriculture sector (FAO, 2000a), and nor have they promoted income generating activities. Such activities are the only way for rural people to break out from the vicious circle of poverty[15].

FAO has been active in assisting developing countries to meet their energy requirements in agriculture, forestry and fisheries as a means of achieving sustainable rural development. An integrated approach to incorporating energy into rural and agricultural planning has been promoted, together with the increased use of modern energy technologies. Activities sponsored by FAO have included, for example, a project in China, which integrated alcohol production from sorghum with biogas, pyrolysis, solar and wind energy systems (FAO, 1994). This work also examined energy conservation and the potential of various renewable energy sources in specific farm activities. The project is presently being expanded to produce ethyl tertiary butyl ether (ETBE) from ethanol. ETBE is then mixed with gasoline and offers reduced air pollution and CO_2 emissions from transport. Trials are planned for Shanghai and Shenyang.

2.10 Food Security

The 1996 Rome Declaration on World Food Security reaffirmed the right of everyone to have access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger. FAO recently reviewed the state of food insecurity in the world and identified that in the developing world, 790 million people do not have enough to eat (FAO, 2000b). **Whilst there are many reasons for this situation, there is scope for improved productivity and food security by increasing energy inputs**

[14] Compared with 7-8% of GDP for industrialized countries; source: FAO, 1995.

[15] Annex A.3 contains some additional findings from recent FAO work on the impact of PV systems in rural development.

in rural areas. The analysis in this Chapter shows, therefore, that there is a clear rural energy gap in the agricultural sector, which needs to be bridged.

All agricultural production has to become commercial to enable long-term food security; as one of the prime inputs to agriculture, energy plays a decisive role in attaining food security. Attempts to alleviate hunger and to promote rural development and food security must be accompanied by efforts to promote the key role of energy, not as a goal in itself but as a vital component of these attempts. In many cases, it seems that the low quality and the meagre amounts of energy available for the food production and supply chain are at the heart of food security problems.

The empirical evidence and examples presented earlier in this Chapter indicate that it is possible to quantify the extent of this gap in energy terms. However, if this gap were to be closed by an over-zealous use of fossil fuels, then some of the adverse environmental and resource utilization issues identified in Chapter 1 will become more pressing. This solution would not offer a sustainable means of tackling the energy gap problem. Development and deployment of renewable energy systems together with improved end-use energy efficiency techniques can provide an alternative means of helping to bridge this gap. A large number of such energy technologies are mature and commercially available, whilst others still require further research or demonstration. Actions to invest in cost-effective systems and to develop the most promising new technologies are needed.

2.11 Impact of Trade on Energy Demand in Agriculture

The recent moves towards opening world markets to a much wider agricultural trade will have an impact on energy requirements in the agricultural sector. Greater international trade will encourage and require more energy for processing primary agricultural products closer to the source of production in developing countries, then transporting, storing and finally distributing these products to industrialized countries. For example, horticultural products often have a high added value and a transportation and storage system between the farm and the end market using a cold-chain or a controlled modified atmosphere is needed to maintain this value. Hence the new trade opportunities point to additional energy intensive applications developing in the agricultural sector, so increasing the level of energy demand in developing countries.

2.12 A New Direction for Energy in Agriculture – the Use of Measurable Indicators

Ways of measuring the sustainability of energy and agriculture and in particular the benefits of improved energy services for agriculture need to be established, so that indicators of progress can be developed. For example, current work on sustainability indicators could be adapted to include energy and agriculture[16]. Such measures would assist the establishment of a bridge between the rural energy and agricultural policy dimensions so that agricultural energy needs can be included in overall energy planning and policy formation. FAO has initiated work in this field and is developing energy indicators of sustainable agriculture. A third linkage is between the environmental dimension and energy use by agriculture, and suitable indicators of this also need to be developed.

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[16] Annex A.1 contains some further details of the work on developing energy and agriculture indicators. The web site <http://www.globenet.org/helio> also has additional information.

Energy problems and solutions for agriculture should always be guided by local economic, environmental and social considerations. Energy policy formation should bring together national energy development policies with the locally perceived priorities. There needs to be increased emphasis on non-fossil fuel alternatives to the provision of energy services in agriculture in developing countries (Best, 1997). These range from the modern renewable energy sources, such as improved biomass conversion (including liquid biofuels, biogas, gasification), solar energy (PV), wind and geothermal energy and small-scale hydropower, to lower energy intensity industries, material and energy recycling and better means of utilizing traditional energy sources, such as improved cooking stoves. In addition, there needs to be improved energy efficiency in mechanical equipment and in drying and separating operations.

The agriculture sector can move towards a path of greater sustainability through the application of improved techniques and practices such as conservation agriculture, organic farming, protecting agro-biodiversity, better water and soil management, and integrated pest management and plant nutrition. Where appropriate a greater level of mechanization and improved food-processing technologies are also important. The main challenge in the medium term for energy in agriculture is to mobilize the changes occurring in both the energy supply and the agricultural sectors to the benefit of rural livelihoods and communities. There is a danger that rural populations could be left behind unless energy policies are directed specifically on their needs. It seems clear from the analysis presented in this Chapter that energy requirements should be appropriately considered and integrated into agricultural and rural development programmes.

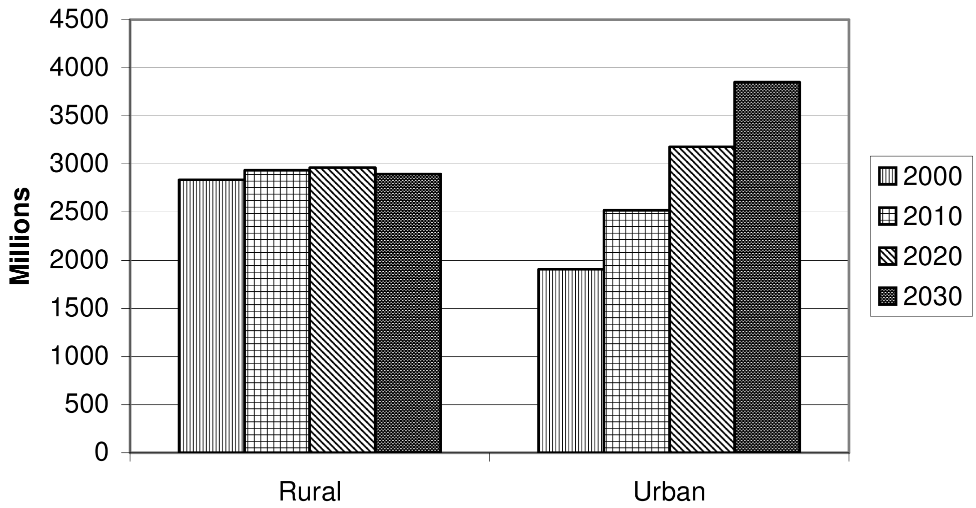
Chapter 3: Rural Energy Supply

3.1 Demographic Trends

The world's population has now exceeded 6 billion people, and growth projections (FAO, 2000c) indicate that the total will be over 8 billion by 2030. More than half the world's population lives in rural areas, and the vast majority of these, some 2.8 billion people, live in rural areas in developing countries. There are 2 billion people without access to adequate, affordable and convenient sources of energy. At least two-thirds of them are dependent on the traditional fuels of woodfuel, dung and crop residues for cooking and space heating. These traditional fuels have low energy conversion efficiencies. Their use, especially in arid and semi-arid areas, can lead to environmental damage through excess stripping of forests and woodlands, and to adverse health effects due to smoke inhalation causing respiratory diseases. Time spent by rural people in gathering and cooking with these fuels involves hard work and drudgery, and is a diversion from other economically useful activities.

Most of the projected population growth is expected to occur in developing countries, and most of that in urban areas. Figure 3.1 shows demographic projections for developing countries up to 2030. The rural population remains almost stable, whilst there are major increases expected in the urban population. Observations suggest that it is the young people that migrate from rural areas to urban centres, whilst an increasingly aged population is left in the rural communities. These broad projections mask some important regional differences. Regional population projections indicate that a large proportion of Africa's population growth will take place in rural areas, contrary to the trends in Asia and Latin America where rural populations are expected to fall in absolute terms. Given the realities of urban growth and the political and administrative pressure to tackle urban problems, it may become more difficult to keep rural energy development on the agenda.

Figure 3.1: Urban and rural population projections in developing countries



3.2 The Challenge of Providing Rural Energy Services

A transition to modern energy systems, some of which may continue to use traditional energy sources, but in new ways, needs to be achieved if sustainable economic activity is to be realised in rural areas. This is a slow process in which traditional energy technologies are likely to co-exist with a gradual improvement and introduction of new technologies accompanying the rural development process. As noted in Chapter 2, energy policies and projects in developing countries have traditionally focused on large capital investments in the generation, transmission and supply of electricity, gas and petroleum products. Such investments have often been concerned with industrialization and urbanization. By increasing access in urban and peri-urban communities to these energy sources, governments have attempted to stimulate growth in productivity and output in response to the socio-political importance of these areas.

Nevertheless, rural energy programmes have been established in many countries. In keeping with the bias to extending the supply of modern energy forms, and because electricity is seen as a flexible and efficient means of accessing modern energy services, most of these programmes have focused on rural electrification. This often involves grid extension into rural areas, but some programmes promote decentralised electricity supply, for example with mini-grids supplied by diesel generators and sometimes with stand-alone renewable energy systems.

For many rural communities there is no immediate prospect of being connected to the central electricity grid, and other commercial energy sources are often too expensive for poor people. However, many rural areas do have local access to other sources of energy, such as solar energy, water streams, wind and biomass. There are opportunities for these resources to be tapped using existing technologies and thereby release a range of useful services.

Moreover, there is a need for urgent action, given the drift of rural populations to peri-urban and urban areas in developing countries. Economic benefits will accrue as a result of improved energy services for rural livelihoods. Agriculture can have a major role in supporting rural livelihoods and community development through provision of locally sourced biomass energy. Improved rural energy services contributes to international development goals, including poverty reduction, better access to water and sanitation and protection of the natural environment.

3.3 Experience of Rural Energy Programmes

The impact and benefits of rural electrification have been examined in many studies. It seems to be accepted that, since electrification is a catalyst for development and not a solution in itself, rural electrification should be part of a much broader development approach. Although priority might be placed on electricity for productive activities, such as food production, agro-industries and small scale rural industries, the reality is that the household and community needs for lighting, space and water heating and small appliance power have received rather more attention. This has occurred through the encouragement and implementation of novel energy supply options such as solar home systems (FAO, 2000a).

The broad experience of rural energy policies has shown that subsidies can distort markets and encourage the uptake of fuels, which are not necessarily least cost, or even best suited to the energy services needed (World Bank, 2000b). Furthermore, the cost of available appliances that use modern fuels can be too high for poor families, especially as the energy end-use technology is often imported. Another difficulty is that supplies of liquid fuels are often insufficient or unreliable, and there is reluctance by rural people to depend on modern fuels due to fluctuations in household income levels, arising from the seasonal nature of agricultural outputs and unstable markets.

Grid extension is not economic for low density energy demands. Low density demand arises from a combination of the dispersed nature of the rural population and the low initial electricity consumption in low income households. High connection and wiring costs can mitigate against households hooking-up to grid supplies even where the supply has reached their village, and despite subsidised tariffs. High first costs can be a barrier to the deployment of decentralized off-grid systems. Supplies are sometimes unreliable or of poor quality. Moreover, by itself, electrification does not guarantee economic development and its benefits tend to accrue to the wealthier groups in electrified areas. Indeed, any correlation between energy investments and poverty alleviation is less well understood. Although there is anecdotal evidence on the direction of links between energy and poverty alleviation, little direct evidence is yet available (World Bank, 2000b).

Simply providing electricity, which can often be the main policy objective, does not tackle the major uses of energy by poor rural households, namely cooking and space heating. Furthermore, it does not impact on economic development unless, as stated above, it is coupled with rural development efforts. In some cases central "top-down" energy programmes have been imposed without local community consultation, involvement or support, and insufficient institutional structures have led to disappointing results. Even in deregulated markets, few financial incentives exist for utilities to invest in rural electrification schemes, and central policy direction from the government can hinder rural energy development. For example, independent power generation is often not permitted, or is controlled very tightly. Legislative and institutional weaknesses can create barriers to the development of local resources, and act as a disincentive for private investors or entrepreneurs to invest in rural energy markets.

The ability of the rural poor to pay for their energy needs is now seen as being greater than previously assumed. Box 3 provides examples of approaches using micro-finance to provide credit for rural energy development involving the application of PV systems, which have been a major focus of off-grid rural energy interventions (UNDP/EC, 1999; and DFID, 1999). Building on such experiences, new directions for rural energy programmes aimed at improving energy services for poor people are being examined (World Bank, 2000b). These include policy actions in the following areas:

- restructuring energy markets in order to facilitate entry and competition, including in the distribution and retailing of services;
- allowing multiple players, small and large, in the construction and operation of secondary networks, and allowing multiple players in projects to expand services to rural areas;
- wherever possible, ensuring that energy prices reflect the full cost of supply;
- where subsidies are necessary, targeting the intended beneficiaries in a manner consistent with competitive provision and exploring innovative financing mechanisms through local micro-credit agencies and community savings schemes;
- changing regulatory processes to allow appropriate service quality standards so as to facilitate participation by low-income consumers;
- taking a more holistic view of the factors affecting energy supply to low-income households and communities.

These approaches are attempts to improve energy service options available to rural households and communities. They also recognize the importance of a more efficient, financially sustainable energy supply sector operating in a market structure.

Box 3: Micro-finance for Rural Energy Using PV Systems

Community associations and cooperatives can bring together local people in planning, managing and financing rural energy projects. By scaling up energy demand they can reduce unit costs and offer greater creditworthiness than is possible for individuals. Examples are:

Bangladesh

The Grameen Bank in Bangladesh has set up a non-profit company, called Grameen Shakti (GS). The company specialises in micro-credit for rural development. GS aims to supply renewable energy technology to rural households and create local employment. Starting with PV systems, GS is offering 24-month leasing financing to consumers to spread out the initial equipment cost. GS estimated that one million Bangladeshi households without electricity would be able to afford these terms. In parallel, GS is training a network of local retailer-technicians to provide on-going maintenance and customer support.

Morocco

In Morocco, the NGO Migrations et Developpement has helped electrify nearly 100 villages in a remote mountainous area through diesel-based mini-grids. Local operators provide electricity to a village cooperative on a fee-for-service basis. The NGO helps the villagers form an association to own, manage and finance the electrical systems. The association raises some 40% of the capital cost and a further 10-20% as costs-in-kind (such as direct labour and supplies), the balance coming from an EU grant. To minimise costs and maximise benefits, bulk purchases are used, and all households must be connected. Least-cost and sustainable tariffs and service standards are negotiated.

Philippines

In a Dutch-funded project in the Philippines, the Development Bank of the Philippines agreed to finance PV solar home systems, but only to village cooperatives in order to avoid the high costs of servicing many individual small loans. The Bank leases out the systems, and hence owns the PV panels as collateral. If a cooperative has to return a PV panel because of payment defaults, the dealer which supplied the system has to agree to buy it back. Another financial safety net is provided by the cooperative's own funds, which can usually carry for a time the payments of individuals who run into financial difficulties.

Sahel Region

Solar PV drinking water pumps and community systems were installed in remote areas of nine countries in the North African Sahel region. The village associations pay for the main project output - water. These payments cover the salary of the villager who manages the system, plus the day-to-day upkeep, the annual maintenance and a deposit fund that is collected for the eventual replacement of the system. All the installation and maintenance contracts are managed by a local company, which benefits from the financial stability of the operational and maintenance fund.

3.4 Sustainable Rural Livelihoods

An emerging theme in development policy is that of "sustainable rural livelihoods". FAO recognizes the concept of promoting sustainable livelihoods as a means to combat food insecurity and rural poverty[17]. The livelihoods concept denotes the means, activities, entitlements and assets by which people make a living (DFID, 1998). **For poor rural people to escape from poverty, they must be able to improve their livelihoods in ways that can cope with, and recover, from stresses and shocks, while maintaining and enhancing their material and social assets and opportunities, both now and in the future, and while not undermining the natural resource base.** Applying this approach, UNDP explicitly focuses on the importance of modern technology as a means to help people rise out of poverty whilst complementing indigenous technologies[18].

One element of this sustainable rural livelihoods approach is to have better access to basic and facilitating infrastructure, and energy is a key component of this infrastructure. Improved energy services can assist more broadly in rural development as well as in food security. For example, the supply of wood-based fuels can be organized in a commercial way that provides income to a large number of people while still remaining sustainable. By appropriate investment in physical and human capital, the development of rural enterprises can be stimulated by improved electrical energy services, and this applies particularly for lighting, small power tools and appliances.

3.5 Modern Biomass[19] and Rural Energy

Modern biomass systems offer an economically promising and environmentally sustainable means of increasing access to improved rural energy services in developing countries. Whilst traditional solid biomass fuels can deliver only poorly controllable heat, modern biomass can provide a variety of efficient and well-controlled energy services. Biomass is stored energy and is not subject to daily or seasonal intermittency. Biomass can produce all forms of energy, electricity, gas, liquid fuels and heat, and its exploitation can provide rural employment, encourage people to remain within their communities, increase profitability in the agriculture sector and help to restore degraded lands.

Biomass can be converted into modern energy carriers through both mature and novel conversion technologies, and has the potential to be a significant source of energy for rural applications. Technological developments in biomass utilization in modular plant have also created new opportunities for rural energy development. Advanced small-scale biomass energy technologies could generate base-load electricity and contribute much to improving living conditions in rural areas. Decentralised rural electrification can provide more jobs in rural areas than central generation. Woodfuel supply is labour intensive, and can involve a series of processes of cutting, collecting, splitting, bundling, charcoal making, packing, transport and trading. Biomass production could be a major source of both jobs and revenues for rural areas, where both energy crops from dedicated plantations and the by-products and residues of other agricultural production can be used as feed-stocks.

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[17] An inter-agency initiative in this topic, which involves FAO, is outlined at <http://www.fao.org/sd/ppdirect>.

[18] The UNDP web site on sustainable livelihoods is <http://www.undp.org/sl>.

[19] See Annex A.2 for a detailed description of biomass definitions and terminology.

Biomass resources vary in type and content, depending on geographical location:

- *temperate regions* - produce wood, crop residues such as straw and vegetable leaves, and human and animal wastes. In Europe, short rotation coppicing has become popular as a means of supplying wood fuel for energy production on a sustainable basis. Fast-growing wood species such as willow are cut every 2-3 years and the wood processed into chips to provide a boiler fuel. In countries where large quantities of municipal wastes are generated, systems to exploit energy from these wastes via incineration or through recovery of methane gas from landfill sites have been developed;
- *arid and semi-arid regions* - produce very little excess vegetation for fuel, and people living in these areas may be affected by desertification and can have difficulty finding sufficient woodfuel;
- *humid tropical regions* - produce abundant wood supplies, crop residues, animal and human waste, commercial, industrial and agro-processing residues. Sugar cane bagasse, rice husks, cotton husks and groundnut shells are all used, particularly for process heat or co-generation.

Wood energy supply

Woodfuels account for an estimated 7% of the world's total energy supply. They are often depicted as a primitive energy form, which is a major cause of deforestation. In practice woodfuel for cooking and space heating comes in large part from non-forest sources and from by-products and forest residues. Managed properly, wood energy supply can be sustainable, environmentally benign and economically sound. There is little real evidence that woodfuel use is a major contributor to deforestation and degradation. Often wood is not burned directly, but is processed into a more suitable form, such as chips and pellets. Wood can also be transformed into a secondary solid form (using pyrolysis, namely heating biomass in the partial absence of air and reducing wood to charcoal or liquids), or into a liquid (e.g. methanol) or gaseous form. Table 3.1 lists some woodfuel definitions and gives examples.

Table 3.1: Woodfuel definitions

Woodfuel type	Brief definition	Examples
Direct woodfuels	Wood produced for energy purposes and used directly as fuel	Woodfuel, charcoal
Indirect woodfuels	Mainly solid biofuels produced from wood processing activities	Bark and sawdust from wood mills
Recovered woodfuels	Wood used directly or indirectly as fuel, derived from socio-economic activity outside the forest sector	Used wooden containers
Wood-derived fuels	Liquid and gaseous products from forest activities and the wood industry	Black liquor from cellulose plants

Wood constitutes the major source of energy for most countries of sub-Saharan Africa, Central America and continental south-east Asia. In 1995 there were 34 countries where woodfuels provided more than 70% of energy needs, and in 13 countries woodfuel provided 90% or more. Table 3.2 lists woodfuel consumption by region for 1995 (WEC/FAO, 1999; and FAO, 1999).

The so-called woodfuel crisis emerged in the mid-1970s as the scale of deforestation in developing countries became apparent. Energy demand appeared to be out-stripping supply, and although the woodfuel resources were renewable, the rate of use appeared to be unsustainable. This analysis was based on the belief that most wood fuels originated from forests. However, more recent studies conducted by FAO have shown that non-forest areas supply considerable amounts of wood fuels. A major part of the supply is derived from non-forest areas such as village lands, agricultural land, crop plantations, field boundaries, homestead areas and roadside trees. These studies have helped create a clearer picture of the reality of woodfuel use.

Table 3.2: Woodfuel consumption and share of total energy use (1995)

Region	**Woodfuels Mm^3 equivalent**			**Share total energy (%)**
	Fuelwood	Charcoal	Black liquor	
Africa	445	131	34	15
Asia (developing)	859	72	3	35
Oceania (developing)	6	0	0	52
Latin America and Caribbean	223	34	19	12
Europe, Israel, Turkey	56	2	51	3
Former USSR	32	0	8	1
Canada and United States	96	4	146	3
Australia, New Zealand, Japan	3	0	23	1
World Total	**1700**	**143**	**284**	**7**

The overall trends in demand and potential supply of wood and other biomass fuels in 16 Asian countries are shown in Table 3.3 (FAO, 1997)[20]. The data show that the aggregated potential supply outweighs aggregated consumption. Deforestation due to conversion of forest land into agricultural land results in an increased supply of biomass fuels, because agricultural land generally has a higher biomass fuel productivity than forest land. The potential supply of biomass fuels from only half of crop process residues is substantial. Field residues, which are about four times the volume of processing residues, are not included in these estimates.

Table 3.3: Consumption and potential supply of biomass fuels in 16 Asian countries

	1994			**2010**		
	Area	**Mass**	**Energy**	**Area**	**Mass**	**Energy**
	1000 ha	kt	PJ	1000 ha	kt	PJ
Total woodfuel consumption		**645,895**	**9,688**		**811,548**	**12,173**
Potential woodfuel supply						
Forest land	416,204	669,812	10,047	370,363	629,339	9,440
Agricultural areas	876,933	601,407	9,021	971,062	692,088	10,381
Other wooded lands	93,140	53,994	810	81,368	47,170	708
Deforestation waste	(4,253)	605,565	9,083	(3,114)	437,710	6,566
Total woodfuel potentially available	1,382,024	1,930,778	28,962	1,419,679	1,806,307	27,095
50% of crop process residues	876,933	218,915	3,458	971,062	322,024	5,105
Total potentially available		**2,149,693**	**32,420**		**2,128,331**	**32,200**

[20] The 16 countries are: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam.

Despite the large size of the potentially available resource, fuel scarcity in localized areas and their unavailability to weaker consumer groups remain serious problems. In reality, woodfuel markets are extremely localised and fragmented, and consumers may not be able to use the available resources due to physical, financial and social constraints. As market mechanisms become stronger, and income distributions become wider, traditional woodfuel consumers may become marginalized. Where woodfuel is not yet a traded item, and its use is for the basic subsistence energy needs of poor people, participatory forest management is likely to remain important. Agricultural applications for traditional biomass include providing fuel for steam boilers to generate heat for tea drying and tobacco curing.

3.6 Biomass Conversion Technologies

Biomass for direct combustion utilizes agricultural and forestry sources, or specialist energy crops grown specifically for energy purposes. Many methods for the conversion of biomass into energy services have been developed, reflecting the diversity of final uses and the nature of the resource. The traditional domestic use of woodfuel, charcoal and agricultural residues is for household cooking, lighting and space heating. The efficiency of conversion of biomass to useful energy in these applications is generally between 5 and 15%. This compares with modern industrial processes using anaerobic fermentation to produce biogas or direct combustion in furnaces to produce either direct heat or steam to supply a turbine for electricity generation which have conversion efficiencies greater than 20% and up to 30%.

The following sections provide an overview of each of the main biomass conversion technologies and their use in rural energy supply applications.

Anaerobic fermentation

Wet wastes such as green agricultural crops, agro-residues, farm slurry, night soil and certain industrial effluent streams such as in beer, sugar and food production and processing can be processed via anaerobic digestion. This produces a methane-rich biogas that can be collected and combusted. Anaerobic reactors are generally used for the production of methane rich biogas from manure and crop residues. They use mixed methanogenic bacterial cultures that are characterized by defined optimum temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range, e.g. from 0^oC up to 60^oC. When functioning well the bacteria convert up to 90% of the feedstock energy content into biogas, containing about 55% methane, which is a readily usable energy source for lighting and cooking. The sludge remaining is non-toxic and odourless and can make good fertilizer since it retains most of its nitrogen and other nutrients.

Anaerobic digesters of various designs have been widely used in China and India. Rural programmes have promoted biogas plant as ideal candidates for village use due to their advantages in energy and fertilizer production as well as the improved health benefits by substituting for inefficient woodfuel use. A further consideration is the need to meet increasingly severe environmental standards regarding liquid and solid effluents from farms and industry[21].

[21] See for example, work in Denmark and Lithuania, <http://www.folkecenter.dk/rokai>.

At the household or community level biogas can be used for cooking and lighting. There are an estimated 5M small-scale digesters currently in use in China and India and perhaps 2000 large and medium sized plant, many of which are located on farms or at agro-industry plant. Subsidies, in either direct or indirect form, have contributed to this development, but there are prospects that a commercial market could emerge, particularly for the farm-based systems. In these larger sizes, biogas can also be burnt in modified natural gas boilers or used to run internal combustion engines for motive power applications. Box 4 describes an example of anaerobic digestion in rural energy supply on two large-scale farms in China (Martin, 1997).

Box 4: Anaerobic digestion on large-scale livestock farms in China

Two examples are given below where anaerobic digestion has delivered via an integrated approach a range of social, environmental and economic benefits. Whilst the main driver for the investments has been increasingly stringent environmental legislation regarding liquid effluents, the additional benefits have reinforced the attractiveness of these systems. However, the systems are likely to be best suited for large farm enterprises, since the majority of poor and small farms would be unable to afford the capital investment. Furthermore, the value of the extra produce is influenced by the close proximity of these farms to a city market that can afford to pay premium prices. Technical support, including training and advisory services, were required from the local rural energy association, and these facilities are not always available in more remote farming areas.

Fushan Collective Farm, Hangzhou

This farm comprises 280 families raising chickens, pigs and fish, as well as growing rice and tea. Two anaerobic digesters have been installed during the late 1990s - a $200m^3$ capacity digester receives waste from 30,000 chickens and a larger $500m^3$ capacity digester receives slurry from 8,500 pigs. The digesters produce biogas, a liquid effluent and a solid sludge. Biogas is used as a cooking fuel in the farm workers' houses, for leaf drying in the tea processing facility and for space heating in the chicken sheds. The liquid effluent is used as a feed supplement for the pigs (from the chicken digester only) and for the fish, and as a crop fertilizer for rice and tomato production. The sludge is also used as an intermittent fish feed and organic fertilizer. The capital costs were paid for by an initial investment from each family on the farm and a small bank loan. The biogas supply to each house and a cooking stove were included in the initial investment. The biogas replaced the use of straw and rice husks as the cooking fuel and this has improved the local air quality.

Xizi Pig Farm, Hangzhou

This farm contains 10,000 pigs. The farm is owned by a local manufacturing company which was able to raise the finance for the digester plant and associated engine/generator equipment. An anaerobic digester of $500m^3$ capacity has been built to process the farm wastes and improve the quality of the controlled liquid discharges from the farm. Pig slurry is collected daily and stored in the anaerobic tank, producing biogas, liquid effluent and sludge. The biogas is used as a heat source for hot water and also in winter for pre-heating waste for the digester, and as a fuel for a 50kW spark ignition engine. The engine drives an electrical generator, which supplies electricity for much of the farm equipment. The liquid effluent is used as a fertilizer and fish feed; the sludge is dried and mixed with potash and phosphate and then also used as fertilizer.

Electricity and heat production in modern biomass technology

Agricultural co-generation using biomass in an agro-industrial plant offers the prospect of producing process requirements for heat and power and the export of any surplus electricity to a local grid distribution system. Underlying this approach is the desire to capture the agricultural, industrial and energy benefits of biomass resources. However, the potential for co-generation varies according to site location and the nature and type of crop, on the capital costs and the economics of the operation. Biomass fuels are not always traded commodities, but are locally collected and transferred to the point of use, and fuel supply security then becomes an important issue.

A secure fuel supply chain, preferably with long-term contracts in place, is needed for co-generation, using sources such as:

- sugar production from sugar cane with a mixture of waste streams. The most plentiful of these is bagasse, which are the remains of the cellulosic structure once the sugar has been extracted. This material, once dried, is combustible and is frequently used as the basis of captive power production in many sugar mills;
- palm oil production residues in the form of fibre, shells and empty fruit bunches;
- rice husks as a by-product of the milling process;
- wood residues from rubber and other forestry based operations.

Biomass gasification uses partial combustion of biomass to form carbon monoxide and hydrogen. The resulting gas mixture can be subsequently combusted in gas turbine plant to produce electricity. Gasification technology offers the prospect of making use of biomass plantations and agricultural residues to produce electricity. Large-scale gasifiers with direct coupling to gas turbines can give attractive gains in efficiency. Such systems take advantage of low grade and cheap feedstocks such as residues and wood produced in dedicated plantations using short rotation coppicing, and together with the high efficiencies of modern gas turbines can produce electricity at comparable cost to fossil fuel plant. Net atmospheric CO_2 emissions are avoided if growth of the biomass feedstock is managed in such a way as to match consumption. The more recent developments of biomass integrated gasifier/steam injection gas turbine plant could operate at energy conversion efficiencies in excess of 40%.

Box 5 gives examples of several biomass combustion and gasification applications for rural energy supply, with electricity production being the main energy output (SEI, 1999; CDC, 1995; and UNDP, 1999). These show that the benefits of biomass can be exploited for the provision of energy services in rural areas.

Bagasse based co-generation has gained considerable momentum in the sugar industries in many developing (and industrialized) countries. For example in India, the technology has been catalysed by a national programme led by the central government and involving state governments and the state electricity boards[22]. The programme offers a favourable policy framework, adequate power buyback rates and attractive financial terms to stimulate investment including subsidies and tax concessions.

[22] USAID support through a GEF grant project has also enabled progress to be made in developing sugar cane co-generation in India. Some additional information on this project is given in Box 9.

Box 5: Biomass combustion and gasification

Co-generation in the Indian Sugar Industry

India is the world's largest producer of sugar. The industry has made significant advances in recent years in developing and implementing sugar cane based biomass co-generation systems, mainly using bagasse as the fuel source. These systems offer an efficient and sustainable energy alternative that can provide process steam and electricity to local industries, while also exporting surplus power to the electricity grid. Around 180 MWe of co-generation plant is currently commissioned in India, with a potential to export to the local grid about 140 MWe. A further 200 MWe is under construction.

Wood-fired power station in Tanzania

Tanzania's first wood fired combined heat and power station was commissioned in 1995. It is owned by the Tanganyika Wattle Company, and has a capacity of 2.5 MWe. The station produces high pressure superheated steam for power generation and lower pressure steam to provide heat for a wattle extraction plant. The total capital cost of the project was US$6 M. The cost of power generated from the plant is significantly lower than diesel generation.

Biomass gasification in Brazil

Biomass has historically played an important role in Brazil's energy supply, contributing to about 30% of primary energy demand. It is also seen as an important energy source for the future with new technologies enabling the efficient conversion of biomass to electricity. Biomass gasification is one of these options. The first commercial power station in the world to use woodfuel in a combined gasification and gas turbine plant is in the State of Bahia, North-Eastern Brazil. It operates by gasifying pre-dried wood chips in an air-blown circulating fluidised bed gasifier. The hot fuel gas produced is then cooled and cleaned of contamination before it is compressed and fed to the combustion chamber of the gas turbine. Exhaust gas from the gas turbine is used to generate steam to drive the steam turbo-generator from which electrical power is produced.

The feedstock for the plant is eucalyptus wood from a dedicated plantation, at a cost of less than US$2/GJ. The net electrical output of the plant is 30 MWe and the capital costs for the gasifier and gas turbine module are around US$1,500/kWe. The system is expected to be competitive with future hydropower generation and with current fossil fuel plant. The project developers include local industry, the local electric utility and a major energy company. The Brazilian Government and UNDP support the project, and part of the investment is funded through the GEF. On a wider scale, demonstration of the commercial viability of Biomass Integrated Gasification-Gas Turbine technology will stimulate its replication in Brazil and elsewhere. The system could be applicable in plant sizes between 20 and 60 MWe, and is capable of offering enormous potential for future electricity generation in rural locations, if it proves economically and technically successful.

Liquid biofuels

Liquid biofuels, usually in the form of alcohol, can be produced from the plant components oil, sugar and starch, and ligno-cellulose containing plants can be converted to solid fuel, methanol, synthetic gas or ethanol. Higher levels of production are obtained using the C4 plant species, which have a more effective photosynthesis and water and nutrient utilization than the C3 plant species. The most important liquid biofuels produced from biomass are ethanol, methanol and rape methyl ester (biodiesel).

Ethanol is of particular importance, since it can readily be used as a fuel for spark ignition engines. It can be produced from a wide range of agricultural products: sacchariferous materials such as sugar cane, sugar beet and sweet sorghum; starchy materials including cereal grains, cassava and potatoes; and cellulosic materials such as miscanthus and short rotation coppice. Table 3.4 lists ethanol yields from a range of agricultural products (Stout, 1990). The basic production process is fermentation by conversion of sugar to alcohol and carbon dioxide through yeast activity. Starches must be broken down into simple sugars before fermentation. The energy content per litre of ethanol is about 65% of gasoline but it has a high octane rating and can be used in more efficient high compression engines. Its low cetane rating makes it inappropriate for direct fuelling of diesel engines.

Table 3.4: Ethanol yields from various products

Product	Yield (litres/tonne)
Wheat, corn, grain sorghum	346-372
Cane and beet molasses	267-313
Sugar cane, sugar beet	92

It is important to calculate the energy balance for ethanol production. Although a major part of the energy input comes from solar energy, there are other inputs associated with crop production, raw material processing and post-fermentation separation and drying. Precise calculations are dependent on assumptions made regarding system boundaries, but in general energy from corn provides little or no energy gain whereas ethanol from sorghum or sugar cane can show a gain of 20-30%.

Methanol can be made from wood, crop residues and other biomass feedstock. The basic process comprises gasification followed by methanol synthesis in the presence of a catalyst, and distillation. However, its cost, toxicity and the need for substantial engine modifications mitigate against widespread use of this fuel.

Production of vegetable oil as a substitute for diesel fuel is a relatively simple process. It involves extracting the oil from the oilseed, filtering, degumming and possibly reducing its viscosity through trans-esterification. Raw materials include sunflower, coconut, rapeseed, palm and olive oils. Once processed, they can be used in existing diesel engines without modification, or can be blended with diesel in varying quantities. Over the last 15 years biodiesel has emerged as a viable alternative transport fuel to petroleum fuel. In Europe biodiesel produced from rapeseed has been stimulated by utilising agricultural set-aside land for energy production, and in the United States, a surplus in soybean oil has been a driving factor. Annual world-wide production of biodiesel is estimated to be over 0.5Mt (IEA, 1998).

A description of ethanol production from sugar in Brazil is presented in the next section:

Making Ethanol from Sugar Cane in Brazil[23]

The Brazilian alcohol fuel programme (PROALCOOL) is the world's largest biomass-to-energy programme, making use of sugarcane as the feedstock for ethanol production. It has been credited with significant environmental and social benefits but it has also been criticized on economic grounds due to the high costs of ethanol relative to the costs of imported petroleum. The rationale for this programme was to reduce Brazil's dependence on petroleum and to help stabilize sugar production in the context of cyclical international prices. The programme began in 1975 and has provided valuable information about the economics, management, agricultural productivity, rural employment and environmental impact of a major biomass-to-energy initiative.

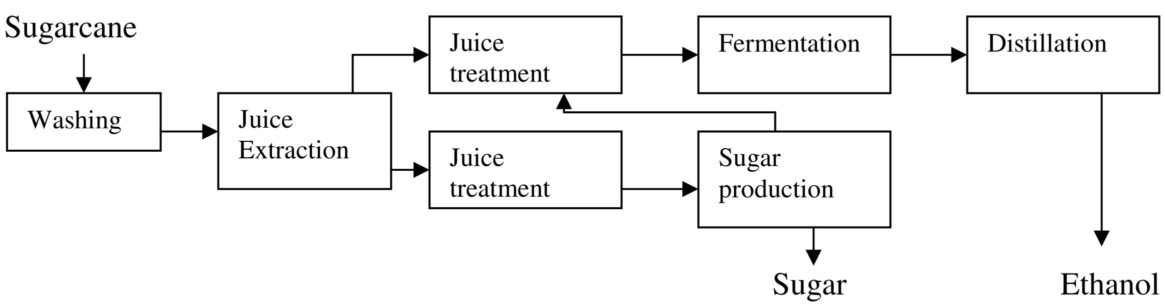
Ethanol makes an excellent motor fuel and is used either as an octane enhancer (78% gasoline, 22% anhydrous ethanol) or as neat ethanol (94% hydrated ethanol, 6% water). As the programme got underway, vehicle manufacturers developed suitable engine technology including dedicated and modified engines for the ethanol-gasoline mixture and straight ethanol products. Ethanol is used as a substitute for gasoline in cars and light vans, and is not used as a diesel fuel replacement in commercial vehicles.

The decision to use sugarcane to produce ethanol in addition to sugar was a political and economic one that required substantial additional investment, and around US$12B (1995 values) has been invested in the programme over the period 1975-1989. Data on ethanol and sugar production from sugarcane in Brazil in 1996/97 are shown in Table 3.5.

Table 3.5: Ethanol and sugar production from sugar cane in Brazil

	Sugarcane	Sugar	Ethanol
Area cultivated (Mha)	4.2	1.5	2.7
Total production (Mt)	273	13.55	13.90
Productivity	65 t/ha	7.6 t/ha	5170 l/ha
Yield (per tonne of sugarcane)		0.14 t	80 l

The different stages involved in sugarcane and alcohol production are indicated below. They differ only in the steps following juice extraction, which is either fermented to produce alcohol or treated to produce sugar. If sugar production becomes less attractive due to reduced prices in the international market, it is possible to shift production to alcohol.



[23] Information in this section derived from Moreira and Goldemberg, 1999; Walter and Cortez, 1999; and de Carvalho Macedo, 1995.

Increases in cane productivity and cost reductions due to improved varieties, better harvesting and crop management and lower transport costs have been made since the programme began. In 1996 there were about 200 combined ethanol and sugar production units, but with different output sizes and conversion efficiencies. Sugarcane grown for ethanol production occupies only 5% of the land area devoted to primary food crops, and uses less land than corn, soybeans, beans and rice. Competition between land for food, export crops and energy crops is not significant in Brazil.

At the outset of the programme, ethanol production costs were close to US$100 per barrel of oil equivalent in 1980, but costs fell rapidly to half that value by 1990, due to economies of scale and technological progress in sugar production and processing. The expectation that alcohol prices would continue to fall so that ethanol would be directly price competitive with gasoline did not materialize. The basic production costs of ethanol are around US$0.21 per litre. Retail ethanol prices were originally set at 64.5% of the gasoline price but ethanol currently sells for 80-85% of the price of gasoline at the pump. To preserve this ratio and to guarantee a remuneration of US$400/$m^3$ of ethanol to producers, there is a cross-subsidy from the sales of conventional transport fuels. Since oil prices in the international market fluctuate while ethanol prices received by producers is subject to government control, mismatches have occurred and the national oil company has incurred losses with ethanol commercialization.

Until 1990, the use of alcohol as a fuel was very successful. By 1990, 4.5M pure ethanol fuelled vehicles had been sold, and ethanol was replacing 50% of the gasoline that would otherwise have been consumed. However, in 1990 the Government launched a programme of cheap popular cars that could not easily be adapted to use pure alcohol at low capital cost. Together with a lack of confidence in a steady supply of ethanol, sales of pure ethanol cars had fallen almost to zero by 1996. The segment of the car market using the 22% mixture of ethanol has not been so badly affected. Overall the share of the transport fuel market taken by ethanol products had fallen from its peak of 50% in 1990 to less than 30% by 1997.

Nevertheless, there have been some major benefits of the programme. These have included the creation of more than 700,000 rural jobs with a low investment cost of around US$ 20,000 each. This has helped to reverse the migration from rural to urban areas and to increase the overall quality of life in many small towns. Improved sugarcane production and sugar and ethanol processing technologies have been developed, and a major renewable fuel programme giving significant savings in hard currency has been implemented over the relatively short time-span of 10-15 years. Furthermore, ethanol fuelled vehicles have had a beneficial effect on local air quality in Brazilian cities. Ethanol from sugar cane also offers a carbon substitution route. The net contribution to atmospheric CO_2 accumulation from the ethanol programme in Brazil in 1996 is shown in Table 3.6. These data take into account the fact that sugar production uses 36% of the sugarcane produced (and almost all its bagasse):

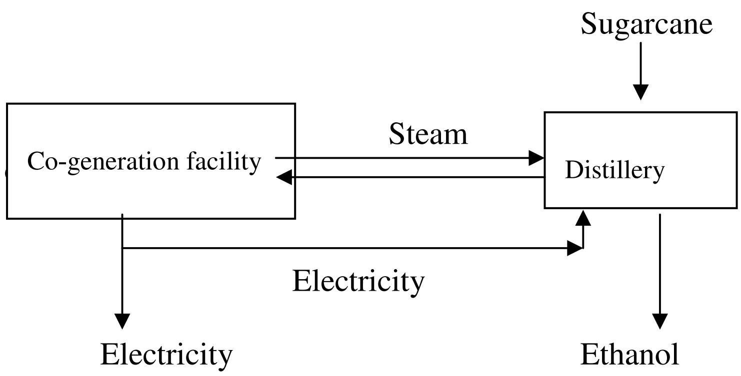
Table 3.6: Net contribution to CO_2 accumulation from the ethanol programme

	10^6 tC (equiv.)/year
Fossil fuel utilization on the agro-industry	+0.82
Methane emissions (mostly burning of residues)	+0.04
Nitrous oxides emissions	+0.15
Ethanol substitution for gasoline	-9.13
Bagasse substitution for fuel oil (food and chemical industry)	-0.87
Net contribution (Carbon uptake)	-8.99

In 1996 the CO_2 emissions avoided with the use of ethanol and bagasse corresponded to nearly 18% of total emissions from fossil fuel use in Brazil. Although this is an important contribution to CO_2 reductions, the cost to Brazil of approximately US$ 200/tC is a significant one if the alcohol programme is viewed exclusively as a carbon substitution programme. Compared with other carbon mitigation options, this is a high cost. However, the social benefits in terms of increased rural employment, and the enhanced job quality and relatively higher wages for sugarcane workers compared with other agricultural sectors are considerable gains for the programme.

The balance between mechanization and the number and quality of new jobs created by the ethanol industry is likely to remain a key issue for several years. Mechanization using higher skilled labour could involve more efficient harvesting, field trash recovery, transportation and raw material conditioning, with fewer lower quality unskilled jobs. With improved cane trash recovery, the power generation sector of the cane processing units could operate for at least 11 months of the year and this would greatly improve the economics of producing energy from sugar cane. The trend will be towards better production technology and higher quality jobs requiring semi-skilled and skilled workers.

There are also techno-economic aspects of new power generation technology that need analysis. Energy co-generation is a common practice in the ethanol processing industry. Bagasse has an energy content of about 2GJ/t and this can be used in a co-generation facility to produce electricity and mechanical power for the mill drivers, as shown schematically below:



Further developments in co-generation technology are possible. Condensing extraction steam turbines are capable of generating an electricity excess of up to 100 kWh/t of cane, and modern biomass integrated gasifier/gas turbine plant can generate an electricity excess of 600 kWh/t. This would require additional investment that can be offset by selling the electrical excess, but the economics depend on the marginal cost of bulk electricity from other sources.

The main lessons learnt from the Brazilian alcohol programme are that:

- production costs need to be reduced still further, including more mechanized harvesting;
- the current market for ethanol in Brazil is insufficient for long-term stability, and ethanol as a vehicle fuel does not compete with oil at current prices;
- the full use of all the energy stored in the sugarcane and its residues is essential to exploit its market, but the economics of electricity production need careful examination;
- the size of the subsidy currently being paid by Brazilian car users remains high;

- the carbon emissions substitution potential of the programme could be developed further in the context of the UNFCCC, Joint Implementation and the Clean Development Mechanism under the Kyoto Protocol;
- development of the use of bio-ethanol as a feedstock for ETBE (ethyl tertiary butyl ether), which can be used in mixtures with gasoline to reduce air pollutants and net CO_2 emissions from transport, can be based on the Brazilian experience of bio-ethanol production.

3.7 The Role of Biomass in Rural Energy Supply

Modern conversion technologies and management practices can provide non-polluting and convenient biomass fuels. As outlined above, experience of bioenergy technology applications can be drawn from a wide range of operating conditions and in many different locations around the world. For example, the electrical loads of water pumping or domestic appliances in rural villages in developing countries are typically in the range 10-250 kWe. A bioenergy gasifier coupled to a small reciprocating engine and electrical generator are well-matched to these loads and biomass derived fuel could replace much of the diesel fuel used in this systems.

There are three major factors in assessing the future role of biomass in rural energy supply (Woods and Hall, 1994):

- the supply of biomass as feedstock can improve the efficiency with which agricultural and forestry land is used in developing countries. In industrialized countries, biomass could provide non-food feedstock from marginal or surplus agricultural land;
- modern biomass production and exploitation offers the opportunity to address multiple environmental concerns such as land degradation, biodiversity, air pollution and health problems;
- biomass as a raw material for high value electricity generation is becoming cost-competitive with fossil fuel energy systems.

The constraints to the development of wider markets for biomass are:

- *land availability* - at the smaller scale of up to 1 MW, which is relevant to rural communities in developing countries, both food and energy crops can be integrated into complementary land use systems. However at the larger scale greater than 1 MW, land use conflicts may occur where dedicated energy plantations are required to supply a central energy conversion facility. Since biomass is a low energy density fuel, transport costs and the security of the supply chain are important considerations, and this may put pressure on nearby food crop production;
- *economics* - typically biomass feedstocks can cost around US$3/GJ, which is comparable with petroleum fuels at around US$2/GJ. The relatively high capital costs of biomass conversion technology are the deciding factor in comparing biomass with fossil fuel alternatives for power generation. However, a useful attribute of bioenergy systems is the ability to add modular increments of power generating capacity;
- *technology development* - whilst certain bioenergy technologies are commercially available or near-market, some of the new conversion technologies are still to be satisfactorily demonstrated, and further R&D and development work will be needed to exploit fully the potential of modern bioenergy for rural energy services;

- *planning and participation* - sustainable biomass production requires detailed local-level planning and the participation of local people, together with a realistic assessment of the biomass resource and the heat and power markets for the energy services provided by biomass exploitation;
- *access to markets at commercial prices* - investors and biomass plant operators need to be sure that there is a external market for the power produced and that this market is not artificially constrained against rural energy generating capacity.

Box 6 presents a case study in Thailand where the regulatory regime has provided a commercial incentive for small electricity producers to develop and sell power from co-generation or renewable energy technology independently of centralized planning by the national electricity authority (Forsyth, 1999).

Box 6: Small power producers in Thailand

Thailand has a well-developed grid-based electrical supply system. During the early 1990s, the government undertook a programme of privatization in order to increase the supply of new power projects and to improve efficiency of operation. Some 60% of new generating capacity between 1996 and 2011 is planned to come from independent power producers (IPPs). Small power producers were introduced as a category of IPPs, with relatively small power capacities of around 50-90 MWe. These comprise specialized users of fossil fuel co-generation plant operated by industrial manufacturers together with renewable energy producers, whose plant capacities are usually <30 MWe. The legislation provides a model of using technology and pricing to integrate renewable energy development into an existing grid system.

The number of IPPs has increased rapidly, with the majority of the supply coming from natural gas and coal fired power plant. However, 24 renewable energy proposals with a total contracted capacity of 189 MWe for export to the Electricity Generating Authority of Thailand (EGAT) grid had been accepted by the end of 1997:

Project type	Number	Capacity (MWe)	EGAT sales (MWe)
Bagasse	14	300	65
Husks, wood chips	9	142	82
Palm oil	1	50	42

One such small power producer is TRT Parawood, located in southern Thailand. The company is one of Thailand's largest rubber wood sawmill operators, with a production of 4,000m^3/month. In the late 1980s the company decided to invest in a 2.5 MWe co-generation plant for internal use and to sell excess power to the grid, and the plant was commissioned in 1996. The plant consists of an automated system for silo unloading, fuel distribution and a boiler feed. The fuel used in waste biomass material from the factory. The boiler produces superheated steam at high pressure, which is supplied to the condensing turbo-generator. Low pressure steam from the electrical generating system is used for kiln drying operations. The total cost of the plant was estimated to be US$2.2M, including civil works and buildings. By producing its own power, the company can save US$840,000/year in reduced energy purchase costs and sell excess power to the grid giving them an estimated income of US$48,000/year.

The description in Box 6 has shown that a key aspect in developing rural bioenergy systems is securing long-term access to local or regional electricity markets for sales of output power. Box 7 provides a description of two further aspects of bioenergy technology development, namely the stimulation of commercial and industrial activities for the design and supply of biomass technology (CO-GEN, 2000), and the use of biomass co-generation to assist in employment generation.

Box 7: Industrial development of bioenergy co-generation

EC-ASEAN CO-GEN Programme

The EC-ASEAN CO-GEN Programme is an economic cooperation programme between the European Commission (EC) and the Association of South-East Asian Nations (ASEAN), coordinated by the Asian Institute of Technology, Bangkok, Thailand. Its aim is to accelerate the implementation of proven co-generation technologies within the industrial sectors of the ASEAN region through partnerships between European and ASEAN companies. The programme provides information services and maintains databases of European technology suppliers and ASEAN potential customers. It is now involved in promoting reference projects in the form of full-scale demonstrations of proven technologies. These demonstrations are meant to be a showcase in ASEAN, aiming to convince other potential end-users to replicate the technologies.

The programme offers a contribution to the investment costs, training for plant personnel and monitoring by an independent organization. Examples of CO-GEN demonstration projects relevant to the agricultural sector include:

Co-generation in a palm oil mill, Malaysia
Palm oil residues are used as fuel for a steam-generating boiler, which produces enough steam for both a 1.2 MW electrical generator and the heat requirements of the mill. The investment costs amount to around US$700,000, energy savings can be made compared to normal electricity purchase from the grid. The expected payback is less than 3 years.

Co-generation in a rice mill, Thailand
Rice husks are used as fuel for a steam-generating boiler, which produces steam for hot water supply and for a 2.5 MW turbo-generator. The investment costs amount to US$4M, and savings in rice husk disposal costs, and reduced fuel oil and electricity purchases mean that the payback time is expected to be less than 4 years.

Use of Biofuels in a Sugar Mill in Nicaragua

Two Nicaraguan sugarmills will generate power from bagasse during the sugarcane season and during the rest of the year from eucalyptus from dedicated energy plantations. This type of power generation is more economic than power generation with fuel oil. It also has positive socio-economic and environmental impacts. Some 73% of the selling price of power from eucalyptus remains in the Nicaraguan economy, while this is between 14 and 30% in the case of electricity from fuel oil. Employment generation is more than 3 times higher in the case of eucalyptus than with fuel oil. CO_2 and acidifying emissions of eucalyptus power generation are about a factor 30 lower than with fuel oil.

3.8 Bioenergy R&D and Technology Development

Solid, liquid and gaseous fuels produced from biomass can replace fossil fuels in many applications. A variety of bioenergy technologies have been developed and several options have emerged that promise to be competitive with conventional power generation options. Indeed, modern biomass furnaces for heat production are already fully developed and economically competitive in many cases. However, the biomass integrated gasification cycle for electricity generation, and combined heat and power production are not yet competitive with fossil fuels at current prices and nor is the production of transport fuels from biomass. Further market development will be required and additional development and demonstration to stimulate new and larger investments, which take more advantage of economies of scale.

One problem with traditional biomass use is the very low efficiency of conversion into useful energy. Biomass use can be modernized through techniques such as co-generation and production of liquid fuels as described above. Much work remains to be done, however, in taking forward bioenergy R&D and technology development, and a substantial level of industrial participation is essential to exploit the potential of biomass. Such work would include (EC, 1997):

- basic R&D on crop forms to improve yields and make better use of available land;
- development of improved harvesting, transport and storage systems;
- technologies to improve combustion efficiency, reduce capital costs and extend the range of fuels that can be burned;
- technologies to improve bio-ethanol production efficiency, including the prospect of new bacterial processes in place of the traditional yeast-based fermentation;
- improvements in gasification and pyrolysis technologies;
- modular designs and performance and safety standards for combustion and power generating equipment.

Involvement by the equipment supply industry, project developers, energy companies, agro-industries, research institutions and local and national government organizations will be essential in order to undertake the necessary R&D and technology development.

Chapter 4: The Energy Function of Agriculture

4.1 Energy in the Wider Agricultural Context

The first and foremost role of agriculture is the production of food and other primary goods and thereby contributing to food security. The concept of Sustainable Agriculture and Rural Development (SARD) aims to foster sustainable development in the agriculture, fisheries and forestry sectors that conserves land, water, plant and animal genetic resources, and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable. Attaining food security requires policies that ensure social, cultural, political, and economic stability. Combining the economic, social and environmental functions of agriculture can help to achieve these goals.

Agriculture can deliver a wide range of non-food goods and services. This can include its use as a viable, sustainable source of energy, as set out in the FAO perspective (FAO/Netherlands, 1999) on the "Multifunctional Character of Agriculture and Land (MFCAL)". The perspective recognises that agricultural activity and related land-use contribute directly to other, non-agricultural functions comprising social, environmental, economic and cultural goods and services. These can result in significant benefits or costs. Evidence suggests that, in addition to food security, agriculture makes a major contribution to achieving sustainability in rural development, energy and the environment at local, national and global levels. The effective operation of the market stimulates the identification and enhancement of these multiple functions and the emergence of new techniques and technologies.

Plant and crop-based resources are used as raw materials for a wide variety of industrial products, ranging from wood used in paper and board manufacture, starches used in adhesives and vegetable oils used in paints and resins. Agriculture provides a key economic sector for the supply of carbo-hydrates, lignins and plant oils, and this supply is renewable over a short time frame compared with the supply of hydrocarbons from fossil fuels. In several industrialized countries there are steps being taken to enhance the use of plant and crop based renewable resources through technological developments (US DOE, 1998).

The role of agriculture as an energy demand sector has been examined in Chapter 2 of this study. Energy is needed for activities such as mechanization, water pumping, irrigation, fertilizer production, transport and food processing and storage. The role of agriculture as a major energy supply sector is rarely recognized or put into practice. **Awareness of the potential for bioenergy as an economic driver for rural development, together with growing attention to global climate change have highlighted this new approach to the energy function of agriculture.**

The traditional rural energy sector in developing countries is already largely based on biomass from agricultural and forestry sources. Woodfuel, especially charcoal, is already very much a traded commodity, and farmers can earn extra income from sale of woodfuels. There is further potential for improvement in woodfuel conversion technologies and stimulation of additional market mechanisms for traditional rural energy, as well as in the development of modern bioenergy technologies in electricity generation, using the experiences outlined out in Chapter 3.

4.2 Energy Supply from Agriculture

The production and use of biomass as energy sources are linked to many issues, including agriculture and food security, land use and rural development, sustainable forest management and biodiversity conservation, and mitigation of climate change. Bioenergy must also be seen in relation to poverty, population development and health. The fact that women and children in many rural areas spend a good portion of their working day in search for fuelwood, reflects the need to look at bioenergy in the context of gender roles and survival strategies for the poorest of the poor.

The imbalances between household economy and the environment needs to be resolved, together with conflicts between conservation and consumption of biomass and between the present and future needs of societies. It is also important to note that ways of producing and distributing conventional energy are changing as a result of new approaches such as privatization, decentralization, trade liberalization and globalization.

The analysis presented in Chapter 3 above has stressed the potential of forest and agro-industrial by-products (residues and wastes) as well as purposely grown energy crops to provide locally available sources of energy in rural areas. Access to adequate and affordable energy is one of the prerequisites for equitable socio-economic development, and use of biofuels can contribute towards a more gender balanced rural employment and income, and can strengthen rural livelihood systems to attain better levels of food security. New and/or improved technologies for bioenergy utilization as an industrial energy source at competitive market prices can contribute towards an improvement of rural livelihood systems.

Set against this approach is the potential threat to forests and trees outside forests if fuelwood is used in an indiscriminately and unsustainable way, which can result in forest degradation or deforestation, deterioration of watersheds, loss of soil fertility as well as biodiversity. Possible conflicts with other land use requirements must also be resolved. Nevertheless the analysis indicates that a substitution of fossil fuels through an increased utilization of biofuels, produced in a sustainable manner, can contribute towards a cleaner environment, reduction of emissions and mitigation of climate change.

4.3 Crops for Energy or Food?

Land availability is often seen as a constraint to the production of energy crops. With many people in developing countries still undernourished, it is a justified concern that there should be sufficient land for food production and that food should be the priority. However, food production is a complex socio-economic, political and cultural issue that goes beyond the earth's carrying capacity to grow food crops. If farmers are given the opportunity through economic incentives, land tenure rights and capital investment, they will be able to produce more food than has been the case so far.

In parallel with the prospects of increased food production, there are large areas of deforested and degraded land that would benefit from the establishment of biomass plantations, with estimates ranging up to over 300 Mha available for reforestation and agro-forestry (FAO/Netherlands, 1999). Other studies of the potential cropland resources in developing countries have indicated that these countries will be using only 40% of their potential cropland in 2025 (FAO, 1996b). The balance between higher yields in good lands and the benefits of bringing back into production degraded lands is an important issue.

Bioenergy programmes, when coupled with agro-forestry and integrated farming, have the potential to improve food production by making both energy crops and income available. Increasing agricultural production of biomass can be achieved by substituting for other agricultural crops that are in surplus, intermixing energy crops with food or forage crops in an agro-forestry approach, and incorporating into land conservation systems such as windbreaks and shelter-belts. There is also potential to increase the use of crop residues provided this is consistent with the levels of organic matter and control of erosion.

Table 4.1 lists some examples of dedicated energy crops, the conversion technologies being developed for their exploitation and the energy and food products that can be produced from them (Overend, 1999).

Table 4.1: Examples of dedicated energy crops

Feedstock	Conversion technology	Products
Sugar cane	Gasification/existing boiler	Electricity Sugar
Switchgrass, wood residues	Gasification/co-firing	Electricity
Sorghum, switchgrass, silver maple, cottonwood	Pyrolysis/combustion turbine	Electricity Charcoal
Willow	Co-firing/combustion	Electricity
Alfalfa	Co-firing./gasification combined cycle	Electricity Animal feed
Pine	Gasification combined cycle Co-generation/alcohol production	Electricity Ethanol
Elephant grass, sugarcane, eucalyptus	Combustion/fermentation	Electricity Ethanol

4.4 Climate Change Mitigation

The threat of climate change is principally an energy-related problem. Current energy systems are based on the combustion of fossil fuels, which account for 75% of the world's primary energy supply. **A second major aspect of the energy function of agriculture, therefore, is the contribution that agriculture can make to climate change mitigation by CO_2 substitution[24].** Carbon sequestration through changes in land management practices are one area of interest, especially as changes such as the introduction of zero-tillage reduce energy consumption in arable farming. Important as it may be, sequestration alone is not a complete solution to climate change mitigation, and carbon sequestration issues are outside the scope of this report, which focuses on carbon substitution opportunities.

[24] FAO is currently examining agriculture’s contribution to carbon sequestration, including issues relating to forestry, land-use changes, and biodiversity. This report does not aim to address these important aspects of climate change mitigation, such as carbon storage in forestry or carbon soil sequestration.

Looking specifically at energy supply issues, biomass offers a carbon-neutral source of energy that is renewable on a short time scale, and hence could provide an attractive means of climate change mitigation. The key aspects that should be considered are:

- the technical potential of CO_2 emissions substitution by the use of bioenergy;
- the technologies that are needed to exploit bioenergy, including their availability, effectiveness and environmental impacts;
- the economics of their exploitation, and the energy markets that can be served by bioenergy technologies;
- the institutional, legal and organizational structures that are required to deliver the assumed benefits.

The Kyoto Protocol is designed to provide binding, quantitative limits on future net emissions of greenhouse gases (for a general description of the Protocol, see the UNFCCC web site at <http://www.unfccc.org>, and Grubb, 1999). Bioenergy could have a major role to play in helping to meet these limits, and mechanisms proposed by the Protocol might make use of agriculture's contribution to climate change mitigation. Whilst the emphasis in international discussions to date has been on forests as a source of carbon sequestration, agriculture also has a major role to play in carbon substitution through the increased use of modern biomass technologies.

Joint Implementation and the Clean Development Mechanism

Joint Implementation (JI) and the Clean Development Mechanism (CDM) are defined under the Kyoto Protocol to the UN Framework Convention on Climate Change as 'flexibility mechanisms' which allow an investor or donor country to fund projects which reduce greenhouse gas emissions (GHG) in a host country. In return the donor country receives 'credits' which contribute to their GHG emissions targets. In JI, a donor country will be an industrialized country with emission targets, whilst the host country will be an economy in transition. In the CDM, a donor country will again be an industrialized country with emission targets, whilst the host country will be a developing country without targets. The credits that will be transferred under JI are called emissions reductions units (ERUs), and those transferred under the CDM are called certified emissions reductions (CERs). Limits on the emissions that can be offset in Annex 1 countries by these mechanisms are likely to be established. It is expected that private sector investors in industrialized countries will undertake either or both of these types of investment if it is cheaper or easier to do so than reducing emissions at home.

The CDM is of particular relevance to developing countries. A cornerstone of the CDM is that projects implemented through it should assist the host country in achieving 'sustainable development'. CDM projects should also be integrated with national development programmes and be appropriate to the specific conditions of the host country. The essential feature of implementing the CDM will be to balance the aim of contributing to the sustainable development of the host countries with the needs of the donor countries to achieve GHG emissions reductions. CDM offers great potential for changing the global approach to development, moving this approach away from the Official Development Assistance framework to becoming a much more private sector led framework. If it is designed properly, the CDM can make a decisive contribution to sustainable development and provide a new channel for finance, investment, technology transfer and the promotion of equity.

Other features of the CDM include:

- project activities must be additional to any policy actions that give rise to the same outcomes;
- it is open to participation by either private or public entities, or combinations of the two;
- projects must have the express approval of the host government;
- an executive board will be set up to supervise the operation of the CDM;
- all CDM projects must be independently certified, possibly making use of operational entities for monitoring and validating emissions reductions;
- baselines and/or benchmarks will be used to assess the extent of emissions reductions;
- CERs can be traded between countries;
- the CDM also has a mandate to use a portion of its proceeds to assist those countries, which are particularly vulnerable to climate change to adapt to those changes.

Projects that are funded via the CDM will be expected to contribute to sustainable development, and renewable energy investments using modern bioenergy technologies are a significant means of achieving this objective.

The CDM is due to begin operation from the year 2000, but, at the time of writing, the detailed rules for its operation have yet to be defined. However, several assessments are available of potential projects and their benefits. Some of these studies assessing the value of carbon emissions avoidance by use of renewable energy systems illustrate the economic potential of agriculture's contribution. Comparing the results of these studies with other climate change mitigation measures, such as fuel switching for grid-based electricity generation (to gas from coal), and improved energy efficiency in industry enable agriculture's contribution as a carbon-neutral energy resource to be ranked against other emissions control technologies. Nevertheless research in this field is only just starting, and no firm policy conclusions can be drawn, especially as the Kyoto Protocol is not yet in force.

Encouragement of international investment from industrialized countries into developing countries as a means of accelerating renewable energy development may be politically sensitive. Whilst international investment could help local development and lead to greater up-take of certain technologies, it may also expose countries to international competition that could damage indigenous industries and increase dependence on foreign technology. These kinds of impact have particular relevance for renewable energy investments where capital costs are high, and where intellectual property remains in the industrialized world.

It seems clear that technology transfer activities need to be treated carefully and that international organizations have to proceed with caution in stimulating these activities. Whether through the CDM or other flexible mechanisms, foreign investment openings for renewable energy systems, including modern bioenergy, would need to be integrated with robust national industrial and technology development policies. Integrating foreign investment and climate change policy is, therefore, not simply about increasing opportunities for private investors, but is equally concerned with establishing the correct combination of market and regulatory factors that allows investors to earn profits whilst delivering public-sector objectives.

Examples: evaluating potential CDM projects in India

Preparatory studies in evaluating potential CDM projects can help to identify prospects and opportunities. As an example, the World Resources Institute (WRI, 1999) has made an assessment of potential CDM projects in Brazil, China and India, in order to review how they might advance both CO_2 emission reductions and sustainable development.

For India, over 20 projects including new technologies for conventional power generation and applications of renewable were examined. All projects broadly advance sustainable development, with benefits ranging from rural electrification and employment opportunities to improvements in productive efficiency. A set of criteria for evaluating sustainable development benefits against India's development objectives was used and each project was scored against these criteria, which were weighted to reflect the importance of different benefits as determined by polling of researchers and government officials.

The results of this exercise are listed in Table 4.2. WRI found that projects advanced under the CDM would make a significant contribution to India's own development goals.

Table 4.2: Evaluation of potential CDM projects in India

Project	Abatement cost (US$/tC abated or removed)	Rank by abatement cost	Rank by overall development benefits
Conventional power generation			
Bagasse-based co-generation	-244	1	1
Combined cycle generation (natural gas)	-133	2	2
Atmospheric fluidized bed combustion	7	3	5
Pressurized fluidized bed combustion	47	4	4
Pulverized coal super-critical boilers	96	5	6
Integrated gasification combined cycle	96	5	3
Renewables for power generation			
Small hydro	29	1	2
Biomass power	134	2	1
Wind farm	216	3	3
PV	1,306	4	4
Renewables for agriculture			
Wood-waste gasifier	169	1	1
Agro-waste gasifier	177	2	2
Wind pump (shallow)	298	3	5
Wind pump (deep)	329	4	4
PV pump	6,333	5	3

Of the abatement opportunities reviewed by WRI, there was considerable overlap between projects that offer low-cost CO_2 reductions and projects consistent with India's development priorities. Whilst projects in different sectors should not be compared, renewable energy systems potentially have a large role to play in assisting both CO_2 emissions abatement and sustainable development. Their importance will be dependent on the procedures agreed for the CDM. Furthermore, assessment of CDM opportunities by national governments and private sector investors will require:

- a least cost approach that places bioenergy and other renewable energy options in competition with other mechanisms and policies;
- a comparative financial and technical risk analysis, from which industrialized country investors may prefer certain types of project;
- assessment of the extent to which particular projects contribute to sustainable development objectives;
- the availability of project finance and political support within developing countries to develop specific carbon abatement options.

4.5 The Role of Bioenergy in Climate Change Mitigation

Bioenergy has played an important part in rural development, but its contribution to an enhanced role in the wider issue of climate change mitigation has not been fully examined in policy formation. Exploitation and commercialization of biomass through modern technologies offers significant cost-effective opportunities for meeting emissions reduction targets while providing additional economic and social benefits. Bioenergy provides a sustainable use of accumulated carbon and acts as a substitute for the use of fossil fuels[25].

All forms of biomass utilization can be considered part of a closed carbon cycle. Biomass utilization through the substitution of fossil fuels will reduce CO_2 emissions, and a combination of biomass with carbon sink options can provide a viable route to climate change mitigation. Consideration of forestation, soil carbon storage and other sink options is beyond the scope of this report, but, as already noted, other work by FAO is being carried out in these topics[26].

The analyses presented in Chapters 2 and 3 suggest that bioenergy can contribute to sustainable development in developing countries, provided that a number of key issues related to the practical exploitation of this resource are carefully considered. Biomass sources are more spatially dispersed than fossil fuels, and whereas dispersion tends to increase harvest and transport costs, modern biomass technologies have the potential for generating employment and assisting economic growth in rural areas. **Current bioenergy sources are mainly forest and agriculture residues, but in the future dedicated energy plantations could provide additional sources, opening up new opportunities for agriculture and forestry in the energy market.**

The world-wide potential for energy supply from energy crops, and the specific use of biomass need to be further examined. There are many complex issues in shifting from petro-chemical feed-stocks; for example, the possible conflict with competition for food crops; the economics of bio-energy resource exploitation; and the availability of land for energy crops. In addition, the role of agronomy in matching species to the objectives of growing energy

[25] Work on the role of biomass in climate change mitigation is being coordinated at IEA Bioenergy by Task 25 "*Greenhouse gas balances of bioenergy systems*".

[26] FAO's current work on carbon sinks and related studies can also be found on the web site <http://www.fao.org/forestry>.

products and to specific local conditions should be examined (Woods and Hall, 1994). **For example, there are opportunities for adapting plant species for production of both food and energy crops in drier zones, where 80% of the world's poor live.**

Plant matter is associated with three basic crops: cellulosic crops, such as wood and cotton; starch crops (such as corn) and oil crops (such as soybeans). Large-scale displacement of petroleum fuels will rely primarily on low-cost cellulosic feed-stocks, whilst starch crops may play more of a transitional role. Such biomass sources have the potential for renewable energy production. IPCC estimated that biofuel production on 10-15% of the land area currently in agricultural use could substitute for about 784 MtC/year of fossil fuel carbon (US DOE, 1999).

In practice, estimating the potential of biomass to offset CO_2 emissions is complex because of the many variables involved such as crop productivity, energy conversion efficiencies and substitution factors. A simplified approach is to use the product of (*cropland area*)x(*crop yield*) as the main factor in determining carbon offset potential. This calculation should then be scaled by an energy substitution factor to account for conversion efficiencies. Based on this approach, estimates of CO_2 mitigation using bioenergy as a direct substitute for fossil fuels can be made. These are achieved by estimating increases in the land area dedicated to biomass production, the extent of better use of agro-forestry residues, and increased efficiency of biomass conversion processes and integrated food-energy production.

Table 4.3 lists a set of recent estimates of the biomass potential for CO_2 mitigation (FAO/Netherlands, 1999). These indicate that energy forestry/crops and crop residues have the potential to reduce emissions of between 500-1600 MtC/year, equivalent to between 8-27% of the current global consumption of fossil fuels. They are broadly comparable with the IPCC estimates. However, these estimates are only for the technically achievable potential, and do not take account of real-world conditions such as market factors that might influence the up-take of biomass technologies for energy supply. Nor do they take account of any policy or institutional constraints that might reduce the opportunities for carbon offsets.

Table 4.3: Potential CO_2 mitigation via fossil carbon offsets using biomass

	Land area (Mha)	Net C yield (tC/ha/year)	Net C offset (Mt/year)	Energy substitution efficiency	C emissions reduction (MtC/year)
Dedicated energy crops: temperate areas	26-73	5-9	130-660	0.65-0.75	80-490
Dedicated energy crops: tropical areas	41-57	6-12	250-680	0.65-0.75	160-510
Temperate shelter-belts	13-26	2-4	30-100	0.5-0.7	10-50
Tropical agro-forestry	41-65	3-6	120-390	0.5-0.7	50-200
Crop residues			350-460	0.6-0.7	210-320
Total			**880-2290**		**510-1570**

Bioenergy should not be regarded as the only means by which agricultural and energy problems can be solved in rural areas; rather it is an option that can provide some benefits in improving agricultural productivity, giving a renewable source of energy supply and helping to deliver a sustainable environment. Its overall contribution depends on a number of inter-related economic, technical, social and environmental factors. The multifunctional character of agriculture and land should, in fact, receive greater recognition so that effective policies and opportunities can be developed to tackle these rural energy problems.

4.6 Exploiting the Potential of Biomass

Biomass offers many potential advantages as an energy supply option; equally there are barriers to be overcome before the full potential can be realised. The balance between advantages and disadvantages is important to assess, and Table 4.4 sets out these features. It is clear that there remain uncertainties about whether and how bioenergy can be developed and commercialized. Large-scale production would require dedicated energy crop plantations, and the cost-effectiveness in any particular investment situation is likely to depend on site-specific opportunities. However, the CO_2 mitigation opportunity may tip the balance in favour of biomass investments if they are regarded as being of global importance, especially if GEF funding, or an appropriate value for CERs obtained through the Clean Development Mechanism, can be used to support the investment costs. These issues, and the steps required to take forward the development of the links between energy and agriculture, are considered further in Chapter 5.

Table 4.4: Exploiting the Potential of Biomass

Advantages	Disadvantages
♦ Biomass is a stored fuel, and can provide a demand responsive supply of energy.	♦ Present-day biomass technology has a poor cost-effectiveness compared with most conventional energy supply options.
♦ Biomass is a flexible fuel feedstock, which can be converted into convenient secondary forms, namely solid, liquid or gaseous fuels.	♦ The ownership of modern biomass technology is largely in industrialized countries, and would require technology transfer for its exploitation in developing countries.
♦ Biomass is a carbon neutral energy source, renewable over a relatively short time-frame	♦ The long-term effects of biomass exploitation, through dedicated energy crop plantations, on soil quality, fertility and biodiversity may be adverse.
♦ Fuel production, collection and supply are labour intensive, which can be an attractive social benefit in rural areas	♦ Biomass plantations may come into conflict with other land uses in competition for high quality land
♦ When developed as part of an integrated approach to wasteland restoration and rural economic development, biomass offers additional environmental, social and economic benefits in rural areas.	♦ A fuel supply chain and a ready market for energy output, with robust and secure contracts must be in place.

Chapter 5: Mobilizing Synergies

5.1 New Approaches to Energy and Development

Renewable energy technologies for developing countries have been the subject of a variety of official assistance schemes. Renewable energy first became an official priority for international aid at the 1981 UN Nairobi Conference on *New and Renewable Sources of Energy*, which called for action in research, planning, investment and dissemination of renewable energy technologies. During the following 10-15 years, there emerged two kinds of initiative: legal or regulatory developments to encourage private investment in renewable energy, and financial assistance to public or private investors from national, bilateral or multilateral sources for capital intensive projects.

However, much of the early international assistance for renewable energy development tended to focus on large-scale projects, and also overlooked the practical needs for promoting technology transfer. Lessons were learnt and the need for a different approach was realized. As an example, USAID reviewed its policies in 1990, and suggested a series of recommendations for industrialized country donors (USAID, 1990). These lessons are equally valid in the planning and assessment of activities for the next decade and beyond:

- only commercially mature technologies should be used in projects that are not explicitly designed to promote technology development;
- only commercially competitive technologies, that are affordable, reliable and easy to service, will succeed;
- local participation and market testing should be required as part of project design, implementation and evaluation;
- fuel subsidies and other policies that hamper the deployment of renewable energy systems should be rectified;
- technological applications should be tailored to fit the local social, economic and institutional conditions;
- maintenance and servicing should be supported as part of the after-sales activities;
- local private-public production, marketing, sales and service are needed to disseminate renewable energy technologies successfully;
- better documentation of past experiences can increase future success.

The discussion in Chapter 1 set out some of the key themes in the relationship between energy and development. New initiatives were designed during the mid-1990s, with the focus changing to an integrated process of encouraging small, local entrepreneurs in developing suitable technologies and then supporting market deployment. More recent experiences of renewable energy programmes suggest that acknowledging local needs and integrating them into technology transfer activities is the best way to ensure that new technologies can be adopted. Policies will also be needed to encourage the private sector, or public-private partnerships, to become involved in improving energy provision in rural areas.

For example, the World Bank has produced a revised set of strategic objectives for its energy policy (World Bank, 1999). These include a larger role for renewable energy systems, creating better links between energy activities and other non-energy sector lending, improving access to modern energy by rural populations to alleviate poverty and projects aimed at reducing the health impacts of traditional fuel use. The Inter-American Development Bank has also included the promotion of new markets for rural energy in its draft energy strategy, and is stimulating renewable energy projects through its Sustainable Markets for Sustainable Energy programme (IDB, 1999).

In the renewable energy sector, the World Bank launched its Solar Initiative in 1994, which seeks to commercialize renewable energy use in developing countries, and has set up the PV Market Transformation Initiative that aims to accelerate the commercialization of solar PV energy services (see Box 1 for additional details). Other initiatives to promote renewable energy by national, bilateral and multilateral agencies have been established in the last few years. Financial and institutional assistance to renewable energy development now tends to address both private-sector needs and improving the regulatory and legislative structure of the energy sector.

Examples of national programmes relating projects combining rural energy and agriculture in developing countries are given in Box 8.

5.2 The Energy-Agriculture Nexus

The analysis presented in this report has suggested that the energy-agriculture nexus is a coherent system, and that energy, biomass and carbon flows can be identified and traced throughout the system. Biomass is an energy source that is renewable over a short time frame, especially if managed annual crops or perennial and short-rotation woody species are used. Sustained economic growth depends on having a secure supply of energy inputs, and biomass can provide an important feedstock for energy systems in developing countries.

The institutional requirements and the policy frameworks that are needed to build on the nexus between energy and agriculture for developing countries are key factors. For this nexus to be fully exploited, the potential of agriculture as a source of renewable energy for rural development and CO_2 substitution needs to feature more strongly in the policy agendas of national, multilateral and bilateral organizations. The cost-effectiveness of using biomass technologies for energy supply, and the associated social and environmental benefits also should form part of this framework.

Bioenergy can and should play a significant role in improving agricultural productivity, whilst at the same time there is a major opportunity for biomass to contribute both to energy supply and global environmental sustainability. The linkages between the energy, biomass and carbon flow elements should form a main focus of rural development and rural energy policy formulation. Developing the potential for bioenergy has also to be seen in relation to poverty alleviation, rural community development and health.

Recognition of the importance of these linkages is now emerging. Technical developments of plant/crop based renewable resources for modern energy conversion systems have been undertaken in many countries over the last 10-20 years, and progress has been considerable. Furthermore, the potential for energy supply from agriculture has gained a higher profile. Box 9 provides examples of the use of agriculture in climate change mitigation through a national climate change policy, a project established under AIJ that links energy and agriculture, and a GEF project involving biomass and co-generation (DETR, 2000; UNFCCC, 2000; and Winrock, 2000). These examples illustrate some of the opportunities by which use of biomass resources, promoting energy development and achieving climate change mitigation can be combined.

Box 8: Rural energy and agriculture programmes

Development of a national biogas programme in Nepal

This FAO project aimed to assist the Government of Nepal in designing and developing a National Biogas Programme and in upgrading the human resources necessary to implement it. The first objective was achieved through the preparation of a National Framework for Biogas Policy in Nepal which should assist in consolidating the Government financial and technical policies for biogas development and serve to develop institutional capacity in the biogas sector. The training of human resources for the implementation of the programme was achieved through the organization of training courses for 130 district level Officers, 150 new local masons, 30 master masons and 150 female biogas users. A training manual was used in five training courses for district level officers. A comprehensive manual on "Biogas Technology: A Training Manual for Extension" was developed.

Mexico - Renewable energy programme

The Mexico Renewable Energy Programme (MREP) is managed by Sandia National Laboratories (USA) for the US Agency for International Development (USAID) and the US Department of Energy (USDOE). It aims to promote the use of renewable energy systems, enhance economic and social development in Mexico, create new business opportunities and off-set greenhouse gas emissions. The focus is on rural, off-grid productive uses of renewable energy systems in off-grid areas, mainly solar and small-scale wind. Productive uses include water pumping for irrigation and/or live-stock, communication and lighting for eco-tourism facilities. The MREP complements programmes by the Mexican Government mainly focuing on Solar Home Systems and is a cooperative effort between governmental and non-governmental institutions from Mexico and USA, including the Mexican Commission for Energy Savings (CONAE), the National Solar Energy Society (ANES), the Center for Energy Research of the National Autonomous University (UNAM), the Shared Risk Trust Fund (FIRCO), Winrock International, New Mexico State University (NMSU) and ENERSOL Associates. Until the second half of 1998, 180 pilot renewable energy projects had been installed, totalling more than 100 kW: 66% PV water pumping, 17% PV Electrification; 3% PV Communication; 1% PV/Wind hybrid electrification; 3% wind water pumping and 10 % wind electrification.

Production of Transport Fuels from Sweet Sorghum in China

Sweet sorghum varieties developed at Shenyang Agricultural University in China are used to produce ethanol for transport. The grain is used for animal feed. Biogas produced from manure is utilized to generate the required process heat. Finally, the squeezed bagasse is converted to pyrolytic biodiesel. This FAO-supported project was successful in these objectives at a pilot scale level. The results of the integrated energy base established are now being used by FAO and the Chinese Science and Technology Commission to scale up this approach with a view of producing ethanol, which will be added to gasoline to reduce emissions of air pollutants and CO_2 from transport.

Box 9: Examples of agriculture in climate change mitigation programmes

UK Climate Change programme: Wood fuelled power station

The UK government has recognised that the most effective way for the agriculture sector to contribute to reductions in greenhouse gas emissions is through the production of energy crops. Ways of encouraging renewable energy generated from forest residues, short rotation coppices and miscanthus are being explored. Short rotation coppice is currently the most suitable energy crop for UK conditions as it is capable of being grown productively on both arable and reasonable quality pasture land. It has one of the highest energy yields and its development as an energy crop is well advanced. Estimates are that 125 kha could deliver a significant fraction of the UK national target of providing 10% of electricity supplies from renewable energy sources, and this could provide a saving of around 0.6 MtC in 2010, depending on the fossil fuel generating plant that are displaced. A current demonstration project of a 10MWe wood-fuelled power station, which uses wood chips from forestry residues and purpose grown short rotation coppice, will provide commercial operating experience of the technology in the UK.

US-Honduras AIJ Pilot Phase project: Biomass Power Generation

A US-Honduras AIJ project involves the construction and operation of a privately owned and operated 15MWe biomass waste-to-energy plant in Sava, Honduras. The plant will utilize wood wastes generated from forest products processing and palm oil production in the region. The wastes, which include sawmill, logging and palm tree plantation residues, are currently burned under uncontrolled conditions, disposed of in rivers or left to decay in place. Power produced by the plant will be sold to the national electricity utility and will displace electricity and greenhouse gas emissions that would have been produced by fossil-fuel plant.

USAID/India Greenhouse gas pollution prevention project

This project is funded out of the US contribution to the pilot phase of the GEF. It began in 1995 and aims to mitigate increases in greenhouse gases through institutional development, capacity building and outreach to key stakeholder groups. One of the main components of the project is providing financial assistance to support demonstration of state of the art co-generation technologies. Much of the work has concentrated on implementing bagasse/cane trash handling, storage and utilization for co-generation, including developing electricity generation both during the cane crushing season and the off-season covering at least 270 days/year.

By early 2000, grant assistance to several sugar mills with a total installed capacity of 88 MWe had been made, together with technical assistance for feasibility studies for co-generation design capacity of a further 85 MWe.

5.3 The Outcome of CSD-8

Agriculture was one of the main themes of CSD-8, held in New York from 24 April to 5 May 2000. The decision on agriculture in CSD-8 provides further support to the importance of the links between energy and agriculture (UNCSD, 2000)[27]. The particular focus of the debate was on promoting sustainable agriculture and rural development (SARD). Three statements are of close relevance to the arguments being presented in this report:

- Governments were urged "*to take a cross-sectoral approach to integrating agriculture in rural development frameworks and strategies so as to maximize synergies and improve coherence*".

- The Conference of the Parties to the UNFCCC was encouraged "*to promote the use of relevant mechanisms to support initiatives in line with national programmes promoting SARD that result in reduced greenhouse gas emissions or carbon sequestration, as well as increased investments in energy efficiency and the use of renewable energy sources*".

- Governments, related international organizations and the private sector were urged "*to continue and increase the transfer of appropriate technology, in particular environmentally sound technology, to developing countries….*"

This recognition of the importance of cross-sectoral approaches, environmental protection and technology transfer presents a major opportunity to energize the agricultural sector in developing countries. In pursuing this approach, developing countries have the opportunity to weaken the historical links between economic growth, energy consumption and environmental pollution. In the rural development sector, this can be achieved by relying more on sustainable energy technologies such as renewable energy systems and by using all fuels more efficiently through energy efficiency programmes. What is needed are integrated energy policies and frameworks, beyond project-specific environmental assessments, in which the costs and benefits of technology options can be assessed and compared on a sector-wide basis, allowing the right choices to be taken early in project design.

Income growth and industrialization in developing countries are driving their economies towards the use of secondary energy carriers that deliver greater end-use energy efficiency. Typical of these carriers are electricity, distributed gas systems and liquid fuels. Modern biomass technologies can provide energy development pathways that meet all these requirements at the same time as offering both global environmental and local socio-economic benefits in rural areas.

5.4 Key Issues

Chapter 1 has shown that energy consumption in many rural areas of developing countries is well below 1 toe/capita/year. This barely covers the cooking, heating and lighting needs of rural people. Present energy consumption and production patterns in rural areas rely on biomass, often used in an inefficient manner. Upgrading the use of biomass resources offers both energy and environmental benefits, and improved energy services can assist more broadly in rural development as well as in food security. An integrated approach, which

[27] See the CSD web site for further information, <http://www.un.org/esa/sustdev/csd8 decision.htm>

captures the full benefits of coordinated actions, supporting rural livelihoods, education, health, sanitation and economic development, is needed.

Agricultural production in developing countries continues to be based on human and animal work. Insufficient mechanical and electrical energy is available for agriculture, and as a result the potential gains in agricultural productivity through the deployment of modern energy services are not being realized. Increased fossil fuel use need not be the solution and non-fossil fuel alternatives can give social, environmental and economic benefits. Agriculture can also provide a legitimate energy supply function. The world-wide potential for energy supply from energy crops is very large and biomass could, in theory, substitute for as much as 25% of the world's use of fossil fuels. Bioenergy can, therefore, make a significant contribution to climate change mitigation through CO_2 substitution.

However, as the summary in Table 4.4 showed, any shift to a greater use of bioenergy is fraught with difficulties. Fossil fuels are not in short supply when viewed over the immediate short-term energy planning horizon, and this has led to complacency and a lack of longer-term thinking. Whilst local environmental concerns such as air pollution from woodfuel combustion, are receiving attention, actions to reduce the global environmental impacts of energy use are not at the top of many agendas. Questions arise concerning development priorities, competing land uses, the cost-effectiveness of biomass technologies, the extent of capital availability and how best to effect technology transfer. The need to pay an insurance premium to cover future global environmental impacts is still seen as many years ahead.

Nevertheless, funding via the GEF or projects using JI and the CDM may offer opportunities to unlock the potential of biomass, through private sector investment from industrialized countries in suitable modern bioenergy technologies in developing countries. At present, however, this approach may have little resonance with current rural energy policies. The key is to make the energy function of agriculture more explicit. Links with the outcome of CSD-8, described above, are particularly relevant in developing worthwhile energy-agriculture initiatives.

5.5 Technology Leapfrogging

Historically most energy technology development has taken place in industrialized countries, where large, rapidly-growing demands created favourable conditions for innovation, and where commercial and industrial interests have found opportunities for profitable markets. In recent years, however, this growth has been confined largely to services and knowledge-based industries, which tend to require very few materials and energy resources. To the extent that innovation is still taking place in the energy sectors of industrialized countries, these are now driven by local and global environmental concerns.

On the other hand, rapid growth in energy producing and energy intensive activities in developing countries is expected to take place over the next 20-30 years. The conditions for innovation in energy technology are likely to be more suitable in developing countries, and hence these countries have an opportunity to stimulate techniques and technologies that could enable them to bypass some of the energy supply and demand patterns of the industrialized countries. **This prospect of technological "leapfrogging" by developing countries could give them the chance to commercialize new technologies relatively quickly, provided there is a strong commercial incentive and a sustained market pull for such technologies.**

Rapid growth prospects in developing countries offer the opportunity for them to become market leaders in environmentally sound energy technologies (UNDP, 1997).

5.6 Impacts on Rural Livelihoods

The rural poor and landless require sustainable livelihood systems that are flexible and not over-dependent on a single resource or product. If large protected areas were managed for bioenergy feedstocks, local people might lose access to other products such as fibre and food. Bioenergy development policy must build in adequate provisions concerning local environmental and social factors, including means of achieving participation and in assessing and monitoring bioenergy activities.

For rural people to benefit directly from bioenergy projects, there need to be checks and balances to ensure that land use changes do not reduce equity. Flexibility to allow for local conditions, which might involve a mix of agroforestry, agriculture and dedicated bioenergy plantations. A robust strategy for developing bioenergy in a way that can assist local rural development should, therefore, include appropriate policies, institutions and community mechanisms.

5.7 The Role of FAO

FAO has a longstanding global mandate from its member countries to promote renewable energy within the agricultural and forestry sectors. FAO has for many years stressed the potential of biomass as a locally available, renewable source of energy and has been active in implementing a range of field projects funded by donor agencies aimed at:

- increasing the supply of biomass, reducing woodfuel consumption and improving the efficiency of end-use;
- promoting renewable energy to enhance agricultural productivity and rural services;
- addressing health problems and gender equality related to traditional woodfuel uses;
- strengthening information and cooperation networks, including data collection and dissemination, awareness raising and capacity building;
- promoting the adoption of biomass issues and actions into national agricultural, energy and environmental policies;
- developing partnerships to take forward biomass activities with other bilateral and multilateral organizations, NGOs and the private sector;
- increasing collaboration with agro-industries with biomass production potential.

FAO is currently strengthening its bioenergy programme with the aim of contributing to a partial substitution of fossil fuels by biofuels, as well as encouraging the more rational, efficient and safe utilization of biomass. A series of further proposed actions for FAO and its national, multilateral and bilateral partner organizations is listed below[28]:

- considering energy and food security as an integrated system to ensure that energy requirements, at all stages of the food production and supply chain, are appropriately considered and supported through agricultural development programmes;

[28] Other recommendations prepared by FAO for PV and sustainable agriculture and rural development are listed in Annex A.3.

- promoting reliable, efficient and economic energy technologies in agriculture, including renewable energy systems and energy efficiency techniques, supported by field projects, technical studies, development of standards and technology transfer activities;
- assessing the costs and benefits of improved energy systems in agriculture, including the effects on agricultural productivity, the environmental impacts, and the social and employment impacts should be undertaken, and disseminating the results widely through national and local organizations in developing countries;
- creating a policy environment in which competition amongst suppliers is encouraged within an effective regulatory framework, whilst taking account of the social and environmental goals of poverty alleviation and sustainability;
- undertaking capacity building, training and institutional strengthening to inform rural energy users and potential suppliers about the technologies that are available;
- carrying out social, economic and technical assessments of the costs and benefits involved in deployment of modern biomass technologies, and identifying the most appropriate technologies and opportunities for deployment in developing countries;
- studying resource potentials, environmental impacts and market integration of energy and agriculture.

5.8 Advancing modern bioenergy technology

For the energy function of agriculture to contribute to the rural economy of developing countries, the potential role of energy production from biomass should receive greater recognition. There is also the need for positive political encouragement and appreciation of the social and cultural changes that might be needed to develop this potential.

There is a balance to be struck between the advantages and disadvantages of bioenergy and this is reflected in both optimistic and pessimistic views regarding the uncertainties about how bioenergy systems can provide cost-effective local and global benefits. These uncertainties have restricted the development and commercialization of modern biomass technologies. However, with the significant environmental pressures to redirect the global energy economy onto a more sustainable path, there is a real and urgent need to reconsider policy choices and commitments in the energy sector. Actions to take the energy sector in new directions are vitally important, and the proposed steps listed above are a first stage in this process, which is applicable to the rural energy sector of developing countries.

It is clear that considerable efforts will be needed in order to take forward the energy-agriculture nexus set out in this report. The technological, environmental and social dimensions need to be further developed and assessed. It is hoped that, by drawing the attention of the CSD-9 to the potential of this nexus, and describing the advantages and disadvantages of modern bioenergy technologies, areas for action can be identified and implemented through cooperative efforts within the international community and with host developing countries.

5.9 A Challenge and an Opportunity

The key tools at the disposal of governments, as they try to open opportunities for rural energy development, are mainly institutional, regulatory and financial. Policies and projects aimed directly at improving energy services for the poor are needed. One means of achieving this is by investments in pilot or demonstration projects that increase market uptake of promising new technologies, with active involvement of local people, NGOs and the private sector. For many developing countries, an energy transition would be characterized by a move from the present levels of subsistence energy usage based mainly on human work and woodfuel resources, to a situation where household, community and agricultural activities make use of a range of sustainable and diversified renewable energy resources.

Energy and agriculture in developing countries has long been considered as a secondary activity, with industrial and urban energy provision taking priority in many national energy programmes. Whilst no single energy source will have a monopoly of supply, it is clear that renewable energy sources in general, and bioenergy in particular, are likely to have larger role in future.

Projects implemented as a result of the Kyoto Protocol could make use of modern bioenergy technologies. Bioenergy projects are already included in GEF activities, and a number of projects have been funded through this route. To help develop these opportunities further, a series of specific related activities could be pursued by the international community. These might include:

- providing assistance to developing countries with the planning and development of national strategies for implementation of the agriculture-related provisions of the Kyoto Protocol;
- development of national and regional capacity for implementation of the Kyoto Protocol;
- development of legal and financial structures for carbon trading and investment in GHG mitigation activities by means of JI and the CDM, including via the World Bank Prototype Carbon Fund (PCF) and any other funding support for climate change mitigation activities;
- verification of national communications and inventories for biomass potential;
- assisting with the identification and implementation of suitable GEF projects involving bioenergy.

The energy function of agriculture needs to be brought to the level of national policy in developing countries. A series of suggested actions for national, multilateral and bilateral partner organizations to mobilize the synergies between energy and agriculture is presented below as the next steps to take. Actions such as energy policy support, institutional strengthening, capacity building, research and development activities and technology development work are important. A prime task should be that of stimulating the integration of energy into the agricultural sector so that emerging policy directions take account of the energy function of agriculture. These actions should have the following features:

- ♦ they should ensure that rural energy projects are sustainable, by tackling and overcoming social, cultural, institutional, legal and financial barriers;
- ♦ they should avoid creating disincentives for investors or entrepreneurs to invest in the growing rural markets for modern fuels and should put biomass and other renewable energy sources on more equal terms with fossil fuels;
- ♦ they should recognize the potential of biomass and renewable energy in general to assist both in the provision of energy services in the rural areas of developing countries and in the transition process to a more sustainable energy supply;
- ♦ they should include the prospect of private sector finance for sustainable biomass projects that have the potential for delivering the energy function of agriculture;

- JI, CDM or other flexible mechanisms agreed by the international community could make use of modern biomass systems. Bioenergy projects are already included in GEF activities. All these opportunities should be developed further;
- for the energy function of agriculture to play its full role, incentives will be necessary to put bioenergy on more equal terms with conventional fuels, and major R&D, technology development and policy gaps need to be addressed.

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Annex

A.1: Indicators of energy use in agriculture

FAO has initiated work on the development of energy indicators of sustainable agriculture. The definition for the basic indicator is the energy utilized in agriculture on a yearly basis expressed as a ratio of energy inputs and agricultural production as well as in absolute terms. This is measured in unit of Joules per tonne of agricultural products, and its purpose is to provide a measure of energy intensity in agriculture.

The development of this indicator is highly relevant to sustainable development. Energy is essential for most human activities, including agriculture. Too little energy makes it difficult to obtain decent productivity and meet food requirements. Too much energy signifies waste, global warming, and other stress on the environment. The indicator can guide policies and investments regarding (i) energy requirements in all stages of agricultural production in order to measure agricultural productivity and, (ii) energy efficiency, to reduce energy intensity. The indicator is relevant to promote an increase in agricultural production with a parallel increase in energy efficiency. The indicator is closely related to the energy indicators under consumption and production patterns. It is also linked to environmental indicators such as land condition change and emissions of greenhouse gases.

Total energy consumption in agriculture derives from the energy inputs in all stages of agricultural production and processing, that is land preparation, mechanization, fertilization, irrigation, harvesting, transport, processing, and storage. Each of these stages uses different forms of energy (mechanical, electrical, thermal) which can be aggregated in equivalent units. Total agricultural production is an established concept and needs no further elaboration.

Annual energy inputs for each stage in agricultural production and processing are determined and converted into equivalent units such as terajoules (TJ) and aggregated as total energy. Annual agricultural production figures are collected for all products. The obtained values are then compared for the same year, and can be tracked over time to see how changes in both terms affect their ratio. At present, no international targets exist or apply. At the national level targets could be developed, depending on the country's range of agricultural products.

Agricultural production is affected by factors other than energy inputs (for example, climate, availability of other inputs). These factors are less distorting if comparative values are collected for consecutive years. Data for energy use in agriculture at the present time are not considered to be very reliable. Special surveys could generate sound data, but would be expensive, and may not be a priority for statistical agencies. The indicator could be expanded to include non-commercial energy inputs, such as human and animal power. Human power quantification methodologies might need to be further elaborated. The relevance of this alternative to sustainable development is questionable.

Data are needed on energy inputs for different agricultural activities and on agricultural production. Some data are available for most countries, although reliable and comprehensive statistics to enable time-series analysis are elusive. Energy balances are prepared by energy ministries or other competent national authorities. Agricultural production figures are available from agriculture ministries. FAO has processed and compiled considerable data in both energy and production at the international level.

A.2: Bioenergy terminology and database[29]

Bioenergy systems are complex and any final energy use can be supplied by different technologies using many kinds of biomass as fuel (Figure A.1). For instance, either sugar (food product) or alcohol (usually for energy) can be produced as a main product from sugarcane, but in both processes an important amount of bagasse is yielded. Bagasse is a solid lignocellulosic by-product, which can be used to produce either heat and electricity by direct combustion, or more alcohol, using acid or enzymatic hydrolysis. Fuelwood can be derived from different sources, both native and planted forests, as well as from by-products of forest industries (sawmills, particle board plants, etc.) and is used by different sectors, such as households, rural industries and commercial activities. This intrinsic complexity is relevant and should be properly considered when a bioenergy database is created.

Figure A.1: Generic Bioenergy System

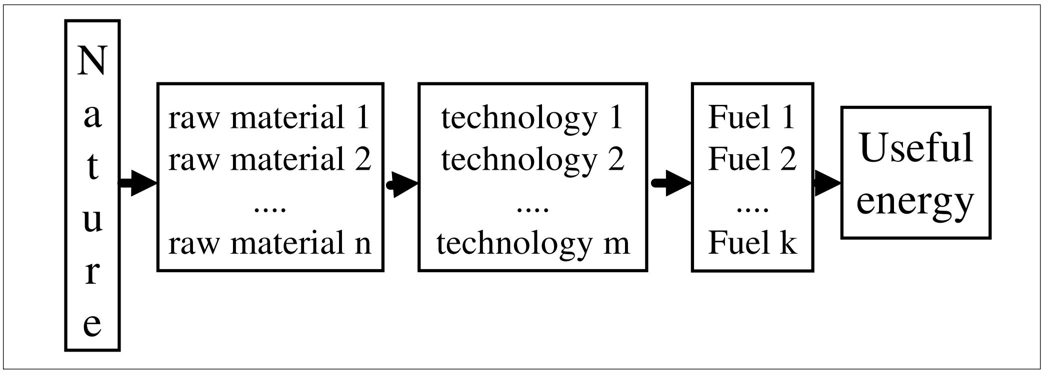


Table A.1 lists a biofuel classification, which recognizes the basic site where biomass production occurs. The groups on the supply side deal with important sub-divisions, which identify the origin of biofuels. On the user side, a variety of fuels can be produced for each group. Listed on the right side of Table A.1 are the different types and qualities of primary, secondary and even tertiary fuels which can be used for heat, electricity and power generation. The secondary and tertiary fuels are often derived from raw biomass produced from different supply sources after the application of more or less complex transformation processes. Brief definitions of the main terms adopted are listed in Table A.2.

[29] Source: FAO proposal under discussion, (FAO, 2000d).

Table A.1: Biofuel Classification Scheme

production side, supply	*common groups*	*users side, demand examples*
Direct Woodfuels Indirect Woodfuels Recovered Woodfuels Wood-derived fuels	**WOODFUELS**	**Solid**: Fuelwood (wood in the rough, chips, sawdust, pellets), Charcoal **Liquid**: Black liquor, Methanol, Pyrolytic oil **Gases**: Products from gasification and pyrolysis gases of above fuels
Fuel crops Agricultural by-products Animal by-products Agroindustrial by-products	**AGROFUELS**	**Solid**: Straw, Stalks, Husks, Bagasse, Charcoal from the above biofuels Dried cowdung **Liquid**: Ethanol, Raw vegetable oil, Oil diester, Methanol, Pyrolytic oil from solid agrofuels **Gases**: Biogas, Producer gas, Pyrolysis gases from agrofuels
Municipal by-products	**MUNICIPAL BY-PRODUCTS**	**Solid**: Municipal solid wastes (MSW) **Liquid**: Sewage sludge, Pyrolytic oil from MSW **Gases**: Landfill gas, Sludge gas

Table A.2: Definition of Biofuel Classifications

1st level	*2nd level*	*Brief definition*
Woodfuels	**Direct Woodfuels**	Wood used directly or indirectly as fuel, produced for energy purposes
	Indirect Woodfuels	Mainly solid biofuels produced from wood processing activities
	Recovered Woodfuels	Wood used directly or indirectly as fuel, derived from socio-economic activities outside the forest sector
	Wood-derived fuels	Mainly liquid and gaseous biofuels produced in forest activities and the wood industry
Agrofuels	**Fuel crops**	Growing plants for the production of biofuels
	Agricultural by-products	Mainly residues from crop harvesting and other kinds of by-products from agricultural activities left in the field
	Animal by-products	Basically excreta from cattle, horses, pigs and poultry
	Agroindustrial by-products	Several kinds of materials, produced chiefly in food processing industries, such as bagasse and rice husks
Municipal by-products		Solid and liquid municipal residues

Detailed definitions

- **Biofuels:** organic primary and/or secondary fuels derived from biomass which can be used for the generation of thermal energy by combustion or by using other technology. They comprise both purpose-grown energy crops, as well as multipurpose plantations and by-products (residues and wastes). The term "by-products" includes the improperly called solid, liquid and gaseous residues and wastes derived from biomass processing activities. There are three main biofuel categories: *Woodfuels, Agrofuels and Municipal wastes*.

- **Woodfuels:** include all types of biofuels derived directly and indirectly from trees and shrubs grown in forest and non-forest lands. Woodfuels include biomass derived from silvicultural activities (thinning, pruning etc.) and harvesting and logging (tops, roots, branches, etc.), as well as industrial by-products derived from primary and secondary forest industries which are used as fuel. They also include woodfuels derived from *ad hoc* forest energy plantations. Taking into account the available database, it is interesting to classify woodfuels into four groups: *Direct woodfuels, Indirect woodfuels, Recovered woodfuels and Wood-derived fuels*, as defined as follows.

- **Direct Woodfuels:** consists of wood directly removed from **Forests** (*natural forests and plantations*; land with tree crown cover of more than 10% and area of more than 0.5 ha);

- **Other Wooded Lands** (land either with a tree crown cover of 5-10% of trees able to reach a height of at least 5 m at maturity *in situ*; or crown cover of more than 10% of trees not able to reach a height of 5 m at maturity *in situ,* and shrub or bush cover); and **Other Lands** to supply energy demands and includes both inventoried (recorded in official statistics) and non-inventoried woodfuels. Direct woodfuels can be divided into primary and secondary fuels, depending on whether they are directly burned or are converted into another fuel, such as charcoal, pyrolysis gases, pellets, ethanol, methanol, etc.

- **Indirect Woodfuels:** usually consists of industrial by-products, derived from primary (sawmills, particle boards, pulp and paper mills) and secondary (joinery, carpentry) wood industries, such as: sawmill rejects, slabs, edging and trimmings, sawdust, shavings and chips bark, etc. They preserve essentially the original structure of wood and can be used either directly or after some conversion to another biofuel.

- **Recovered Woodfuels:** refers to woody biomass derived from all economic and social activities outside the forest sector, usually wastes from construction sites, demolition of buildings, pallets, wooden containers and boxes, etc., burned as they are or transformed into chips, pellets, briquettes, powder, etc.

- **Wood-derived fuels:** refers to woodfuels produced in the forest sector, which require several thermochemical processes before use. They do not preserve any trace of the original wood's physical structure, as is the case with black liquor and methanol produced from wood.

- **Black liquor**: is the alkaline-spent liquor obtained from the digesters in the production of sulphate or soda pulp during the process of paper production, in which the energy content is mainly derived from the content of lignin removed from the wood in the pulping process.

- **Agrofuels**: fuel obtained as a product of agriculture biomass and by-products. It covers mainly biomass materials derived directly from *fuel crops* and *agricultural, agroindustrial and animal by-products*.

- **Fuel crops**: is employed to describe species of plants cultivated on fuel plantations or farms to produce raw material for the production of biofuel. The fuel crops can be produced on land farms (manioc, sugar cane, euphorbia, etc.), on marine farms (*algae*) or in fresh water farms (*water hyacinths*). The land-produced fuel crops can also be classified under: *sugar/starch crops, oil crops and other energy crops*. **Sugar/starch crops**: are crops planted basically for the production of ethanol (ethyl alcohol) as a fuel mainly used in transport (on its own or blended with gasoline). Ethanol can be produced by the fermentation of glucose derived from sugar-bearing plants (like sugar-cane) or starchy materials after hydrolysis. **Oil crops**: cover oleaginous plants (like sunflower, rape, etc.) planted for direct energy use of vegetable oil extracted, or as raw material for further conversion into a diesel substitute, using trans-esterification processes. **Other energy crops**: include plants and specialized crops more recently considered for energy use, such as: elephant grass (*Miscanthus*), cordgrass and galinggale (*Spartina* spp. and

Cyperus longus), giant reed (*Arundo donax*) and reed canary grass (*Phalaris arundinacea*).

- **Agricultural by-products:** are mainly vegetal materials and by-products derived from production, harvesting, transportation and processing in farming areas. It includes, among others, maize cobs and stalks, wheat stalks and husks, groundnut husks, cotton stalks, mustard stalks, etc.

- **Agroindustrial by-products:** refer to food processing by-products, such as sugar-cane bagasse, rice/paddy husks and hulls, coconut shells, husks, fibre and pith, ground nut shells, olive pressing wastes, etc.

- **Animal by-products:** refer to dung and other excreta from cattle, horses, pigs, poultry and, in principle, humans. It can be dried and used directly as a fuel or converted to biogas by fermentation. **Biogas**: is a by-product of the anaerobic fermentation of biomass, principally animal wastes by bacteria. It consists mainly of methane gas and carbon dioxide.

- **Municipal By-products:** refer to biomass wastes produced by the urban population and consist of two types of products: solid municipal by-products and gas/liquid municipal by-products produced in cities and villages.

- **Solid municipal biofuels**: comprise by-products produced by the residential, commercial, industrial, public and tertiary sectors that are collected by local authorities for disposal in a central location, where they are generally incinerated (combusted directly) to produce heat and/or power. Hospital waste is also included in this category.

- **Gas/liquid municipal biofuels:** correspond to biofuels derived principally from the anaerobic fermentation (biogas) of solid and liquid municipal wastes which may be land-fill gas or sewage sludge gas.

The most commonly used types of woodfuels are *fuelwood and charcoal*, which can be burned in both traditional and modern energy systems for cooking, heating or power. These main woodfuels can be recognized under this category (fuelwood and charcoal) even when other fuels, such as chips, wood powder, pellets, briquettes, methanol, ethanol, pyrolysis gases, producer gas, etc., can also be derived from the previously mentioned main supply sources.

- **Fuelwood:** includes "wood in the rough" in small pieces (fuelwood), chips, pellets and/or powder derived from forests and isolated trees, as well as wood by-products from the wood products industry and from wasted wood products. When needed, fuelwood can be prepared into more convenient fuels, such as chips and pellets. **Chips**: wood that has been deliberately reduced to small pieces from wood in the rough, or residues suitable for energy purposes. **Wood pellets**: can be considered as a fuel derived from the auto-agglomeration of woody material as the result of a combined application of heat and high pressure in an extrusion machine.

- **Charcoal:** refers to a solid residue derived from the carbonization, distillation, pyrolysis and torrefaction of wood (from the trunks and branches of trees) and wood by-products, using continuous or batch systems (pit, brick and metal kilns). It also includes charcoal briquettes, made from wood-based charcoal which, after crushing and drying, is moulded (often under high pressure), generally with the admixture of binders to form artefacts of even shapes.

Parameters and Units

Energy sources and commodities may be measured by their mass or weight or still volume, but the essential factor is the energy content related to these sources and commodities. That energy worth must be evaluated in terms of energy parameters, always using standard units. This standardization in the recording and presentation of original units is a primary task of energy and forestry statisticians before quantities can be analyzed or compared. It is recommended that for international reporting, and as far as possible in national accounting procedures, energy and forestry statistics should use the International System of Units, officially abbreviated to SI. Two basic relationships for bioenergy evaluation are introduced as follows, keeping in mind that both the **heating value** and **density** depend mainly on the **moisture** of the biofuel.

$$\text{Energy} = \text{Mass x Heating value} \quad (1)$$

$$\text{Mass} = \text{Volume x Density} \quad (2)$$

- **Mass**: most solid biofuels, such as wood and agrofuels, are measured in units of mass, as are many liquid fuels. The principal units of mass used to measure energy commodities include the kilogram and the metric ton. The metric tonne is the most widely adopted.

- **Volume**: units of volume are original units for most liquid and gaseous, as well as some solid, fuels (woodfuel, charcoal, etc.). The basic SI units of volume are the litre and the kilolitre, which is equivalent to the cubic metre. The stere or stacked volume, usually considered as equal to 0.65 solid cubic meter, has been widely used in the past when measuring the woodfuel volume. Current preference is to measure timber and fuelwood using **solid volume** units, usually in cubic meter. One advantage of measurements by volume is the relatively small influence of the moisture content of the wood on the measurement results. The more water per unit weight, the less fuelwood. Therefore, it is imperative that the moisture content be accurately specified when fuelwood is measured by weight.

- **Density**: the density of wood, i.e., the weight per unit of volume, varies widely between different wood species and types. The density of an air-dried hardwood, such as mahogany or ebony, is around 1 000 kg/cum. The air dried density of a really lightweight wood, such as balsa, is as low as 160 kg/cum. The usual species used for fuelwood are around 500 and 600 kg/cum.

- **Moisture**: the amount of water in biofuel affects, in a decisive manner, the available energy of every biofuel. Two methods (dry and wet basis) are commonly used to specify the moisture content, depending on the adopted basis used to account for the water mass. It is important to distinguish between them, especially when the moisture content is high.

$$\text{Moisture}_{\text{dry basis}} = 100 \text{ x} \left(\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \right) \quad (3)$$

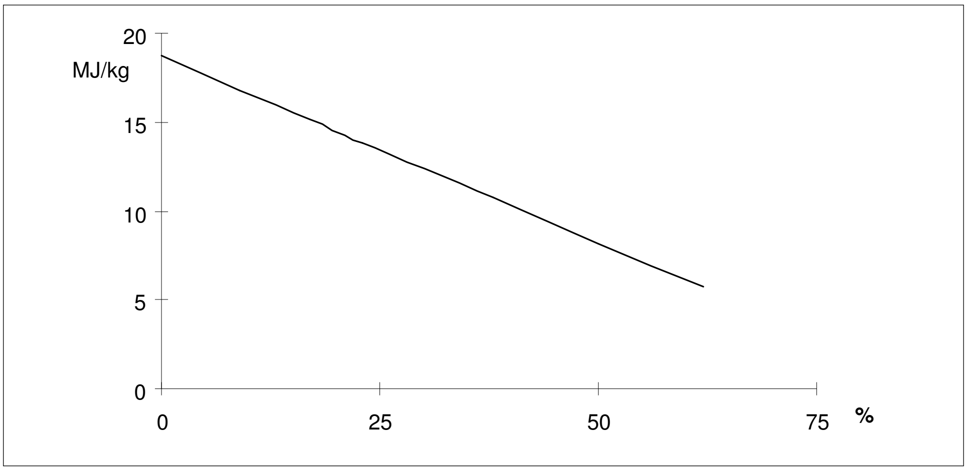
$$\text{Moisture}_{\text{wet basis}} = 100 \text{ x} \left(\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight}} \right) \quad (4)$$

The **wet weight** refers to the burned condition and the **dry weight** refers to wood after a standardized drying process. It is important to state on which basis the moisture content is measured.

- **Ash content**: another important factor of the biofuel energy content is the ash content, always measured on the dry basis, which refers to the solid residue remaining after the complete combustion. While the ash content of fuelwood is generally around 1%, some species of agrofuels can register a very high ash content. This affects the energy value of the biofuels since the substances that form the ashes generally have no energy value. Thus dry woodfuels with a 4% ash content will have 3% less energy than biomass with a 1% ash content.

- **Heating value** (or **calorific value**): biofuel is essentially a material for burning as fire or as a thermal source of energy. The amount of thermal energy stored can be measured through the heating value or calorific value of fuels. The **higher heating value (HHV),** or **gross calorific value (GCV),** measures the total amount of heat that will be produced by combustion. However, part of this heat will be locked up in the latent heat of the evaporation of any water existent in the fuel during combustion. The **lower heating value (LHV),** or **net calorific value (NCV),** excludes this latent heat. Thus, the lower heating value is that amount of heat which is actually available from the combustion process for capture and use. The higher the moisture content of a fuel, the greater the difference between GCV and NCV and the lesser the total energy available, as shown in Figure A.2.

Figure A.2: Effect of moisture (wet basis) on heating value



Charcoal - When statistically recording the conversion from fuelwood (or woodfuels) to charcoal, three principal aspects must be dealt with: wood density, moisture content of the wood, and the means of charcoal production. The yield of charcoal from fuelwood, using different types of kiln, is presented in Table A.3. (165 kg of charcoal is produced from one cubic meter of fuelwood).

Table A.3: Fuelwood required for charcoal production (m^3/ton of charcoal)

Kiln type	Fuelwood moisture (%, dry basis)					
	15	20	40	60	80	100
Earth kiln	10	13	16	21	24	27
Portable steel kiln	6	7	9	13	15	16
Brick kiln	6	6	7	10	11	12
Retort	4.5	4.5	5	7	8	9

Agrofuels - The energy values of agricultural by-products are determined by its moisture content and its ash content. Data for these energy sources are rarely collected directly but are derived from crop/waste or end-product/waste ratios. Bagasse is used as a fuel mostly for the sugar industry's own energy needs, but surpluses are sold to the public grid in many sugar-producing countries. Table A.4 presents data for typical agricultural by-products.

Table A.4: Energy data for selected agricultural by-products

Product	Moisture (%, dry basis)	Approx. Ash content (%)	LHV (MJ/kg)
Bagasse	40-50	10-12	8.4-10.5
Groundnut shells	3-10	4-14	16.7
Coffee husks	13	8-10	16.7
Cotton husks	5-10	3	16.7
Coconut husks	5-10	6	16.7
Rice hulls	9-11	15-20	13.8-15.1
Olives (pressed)	15-18	3	16.7
Oil-palm fibres	55	10	7.5-8.4
Oil-palm husks	55	5	7.5-8.4
Corncobs	15	1-2	19.3
Rice straw and husk	15	15-20	13.4
Wheat straw and husk	15	8-9	19.1

The main factors to be used for bioenergy accounting cover several kinds of biofuels and considering the usual information available from primary data sources. The objective here is to obtain the energy worth of a mass or volume flow of some biofuel, so expressions (1) and (2), already presented above, must be used. However, taking into account the substantial variations in heating value and volume with moisture, it is advisable to express the values of biofuels in a dry and without ash basis, especially for accounting in energy balances. Table A.5 presents values for density and the heating value for typical moisture content.

Table A.5: Basic parameters in accounting biofuels

Biofuel	Primary Data	Density (kg/cum)	LHV (MJ/kg)	Moisture (%, dry basis)
Direct Woodfuels	Volume	0.725	13.8	30
Charcoal	Mass, volume		30.8	5
Indirect Woodfuels	Mass, volume	0.725	13.8	
Recovered Woodfuels	mass, volume	0.725		
Wood-derived fuels	mass	-		
Black liquor	mass			
Methanol	mass		20.9	0
Non-forest Biofuels	mass	-		
Ethanol	mass		27.6	0
Agricultural by-products	mass	(see Table 4)		
Animal by-products	mass	-	13.6	
Agroindustrial by-products	mass	-		
Bagasse	mass	-	8.4	40
Municipal wastes	mass	-	19.7	-

A.3: Recommendations to promote Photovoltaics for Sustainable Agriculture and Rural Development

The following is a package of recommendations arising from the FAO study directed at promoting cooperation between institutions from the energy, agricultural and rural development sectors with the aim to use the opportunities that PV systems offer in contributing to Sustainable Agriculture and Rural Development (FAO, 2000a). These recommendations are the result of an assessment of the experiences collected in this study, enriched with other discussions and inputs. They are intended to provide a set of activities for different stakeholders involved in the process of PV electrification and rural development. It is clear that the main responsibility for action lies with national development authorities. The role of technical cooperation agencies such as FAO is to support these national efforts.

Policy and planning

- National governmental policies need to be established to promote the important role that renewable energies in general, and solar photovoltaic systems, in particular, can play in achieving sustainable agriculture and rural development;
- these policies should guide the establishment of plans, programmes and targets of the agricultural, energy and environmental sectors, and should also create the appropriate environment and the necessary regulatory and normative context for the role of the private sector and non-governmental institutions;
- synergies as identified when PV applications are promoted simultaneously in various sectors of rural society, should be built into policies and programmes;
- policies in the electricity sector should establish the role of independent power producers and the rules to be followed by both power producers and purchasers;
- policies and programmes should also establish the nexus with international efforts to reduce CO_2 emissions and fulfil the goals and targets of the Climate Change Convention and the Kyoto Protocol;

Research and development

- Research is further needed to assess the replicability of promising PV applications and the conditions under which they are successful;
- further research efforts are required for the optimization of PV systems for agricultural use (panels, electronics, applications and end-uses), in order to develop optimized services or product packages, e.g. optimized irrigation systems (panels, electronics, pumps and drip-irrigators) for economic irrigation and fertilization;
- such efforts should be accompanied by assessment of the life cycle technical and economic behaviour of theses PV systems, and by the development of accompanying training and dissemination programmes;
- other areas of continued research and development are low energy consuming appliances (such as affordable low energy consumption refrigerators) and PV/diesel and PV/wind hybrid energy systems;
- research should also include the development of quality standards, e.g. for agricultural applications, in combination with mechanisms to implement these standards;

Finance

- Rural and agricultural development banks should include PV systems as eligible for loans;
- innovative financing channels should be explored, including the possibility of applying the CDM to PV systems; it is expected that investments in productive uses (agriculture) of PV will be easier to finance than Solar Home Systems because of the income generated by the former;
- as for many other products, equal access to credit by women is required, which would increase their chances to use PV for household and income generating opportunities;
- private sector investments can and should be attracted for financing of PV electrification programmes; international donor funds, soft terms loans and other seed capital can be used as a leverage for such private sector investments.

Demonstration, implementation and marketing

- Demonstration and promotion are required for PV applications such as drip-irrigation, cattle watering, PV electric fences and aquaculture applications, to be integrated in agricultural development programmes;
- demonstration and promotion of small PV systems for small cottage industry activities are needed to increase the awareness and knowledge of PV contribution to micro-enterprise development. A possible and innovative approach could be based on *PV powered micro-enterprise development zones* or *business incubator*, through the installation of multi-purpose or multi-service PV units, that can deliver power for income generating activities and common access to phone/fax/web;
- demonstration projects, not done in isolation, but as an intrinsic component of an implementation plan, should include all main stakeholders, including the private sector and government; results of these demonstration efforts should be made public;
- subsidies, when necessary, should be transparent, targeted and time-framed within a gradual phase-out plan; otherwise subsidies should be limited to those PV applications for basic social services such as education, health care, etc.;

Training/information/education/awareness

- Agriculture and other rural extension services should become agents to identify potential PV applications; information and training in this field is required;

- training packages are required for preparing PV installation, operation, maintenance and repair services, but also in the use of PV for various agricultural applications, e.g. improved irrigation techniques;
- particular attention should be given to information and training of women, as main users especially of household systems, and academic curricula at all levels should be prepared and incorporated into educational programmes.

Institutions

- The complex institutional set-up behind SARD needs to be "energized" by the institutions dealing with energy, in general, and with PV systems, in particular;
- to this end, intersectoral efforts are required to bring closer the plans, programmes and policies identified above; this involves the agriculture, energy, health, education and environmental sectors in particular;
- such intersectoral collaboration is critical since small renewable energy systems can have a significant and durable impact on rural development if applied in "packages" in, for instance, agriculture and social services (e.g. communication, education, health care);
- synergies as identified when PV applications are promoted simultaneously and in an integrated approach in various sectors should be built into collaborative implementation and marketing strategies;
- there is a scope for developing a plan for action for the integration of rural energy delivery programmes with micro-enterprise development programmes; mutual benefits could be gained: PV electricity rural markets can become a source and stimulus for both Energy Service Companies and for small "electrified" entrepreneurial activities;
- since PV systems normally require more involvement of the end-user than conventional grid electricity, the involvement of farmers' and other end-users' organizations in all phases of PV programme design and implementation is critical; failure to achieve ownership will most probably lead to failure of the programme.