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154

Forests and energy

Key issues

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Contents

Tables

Figures

Boxes

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This publication consolidates and synthesizes two more comprehensive studies commissioned by FAO in 2007 and published as working papers. They are *Forests and energy in developing countries* by Ivan Tomaselli and *Forests and energy in OECD countries* by Warren Mabee and Jack Saddler. These papers can be found at www.fao.org/forestry/energy. A draft version of the consolidated paper, prepared by Douglas Kneeland and Andrea Perlis, was distributed at the FAO Conference Special Event: Forests and Energy in November 2007. The present edition, revised by Jeremy Broadhead and edited by Maria Casa, incorporates comments received from member countries. Miguel Trossero, Simmone Rose, Sebastian Hetsch and Gustavo Best also contributed.

Foreword

Forests and energy are at the centre of the global debate on climate change. This publication addresses some of the most important trends in both these sectors to enlighten the debate.

The paper draws upon two comprehensive studies commissioned by FAO in 2007: *Forests and energy in developing countries* (Ivan Tomaselli, Brazil) and *Forests and energy in OECD countries* (Warren Mabee and Jack Saddler, Canada). These working papers are available in English on the FAO Web site at www.fao.org/foresty/energy.

Up until 100 years ago when petroleum became widely available, wood was the most important source of energy for human beings. In many of the world's poorest countries, wood remains the primary source of energy for heating and cooking. In this study, we look into the future and see that wood is once again likely to emerge as a very important source of energy in all countries.

Bioenergy from wood and agricultural sources will regain its importance. Agricultural and forest crops play a particular role in modern bioenergy generation as sources of liquid biofuels. While fossil fuels are likely to remain the dominant source of energy for some time to come, a long-term and gradual partial conversion from fossil fuels to solid and liquid biofuels is an increasingly likely scenario for many countries in the coming decades. Will these trends have an impact on forests? Will they result in more or less forest in the future?

This publication explores these questions and more as a contribution to informed policy discussions. It outlines potential opportunities and impacts in relation to forestry in the context of growing global energy demand. Expected changes in global energy supply and the position of renewables and forest energy within this are discussed in Section 2. Aspects of bioenergy production are summarized in Section 3, and Section 4 reviews the possible contribution of forest energy to global energy consumption in the coming years. Section 5 examines the implications of increased consumption of bioenergy on forests, and Section 6 outlines policy options and recommendations in light of the opportunities and threats to forestry.

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Executive summary

Soaring energy consumption, increasing greenhouse gas emissions and concerns over energy import dependence are prompting global changes in the sources from which energy is expected to be derived in the coming years. Energy consumption is projected to increase at the highest rates in developing countries and particularly in Asia. Fossil fuels are expected to account for the bulk of the increase in energy supply. Although per capita levels of consumption will remain below those in the industrialized world, energy consumption in developing countries is expected to surpass that of developed countries by 2010.

Alternative forms of energy are receiving considerable interest as a means to reduce fossil fuel consumption and limit greenhouse gas emissions. Bioenergy, including wood energy, constitutes a large proportion of current supply from "renewable" sources of energy. In spite of the recent oil price increases, it is unlikely that markets alone will support a major reorientation towards renewables and future consumption will therefore depend largely on policy measures.

Wood energy has been used for thousands of years for cooking and heating. In many of the world's developing countries, it remains the primary source of energy and in much of Africa total consumption of woodfuel is still increasing, largely as a result of population growth. In other developing regions consumption at the national level is generally falling as a result of rising levels of income and increasing urbanization – two factors which lead to increased use of more convenient fuels. In industrialized countries and particularly countries with large wood processing industries, wood energy is used for both domestic and industrial purposes – often in significant amounts.

Wood energy produced with efficient technology is already competitive with fossil energy in many countries and can offer some of the highest levels of energy and carbon efficiency among bioenergy feedstocks. Most notably, combined heat and power plants have conversion efficiencies of up to 80 percent and wood pellet stoves have similarly high rates of conversion. It is expected that technology will also be available in the medium-term for commercially competitive production of liquid biofuels from cellulosic materials including wood, although costs associated with patents and royalties may hold back development. Liquid biofuels are currently produced mainly from food crops and economic and carbon efficiencies are mostly low. The notable exception to this rule is the production of ethanol from sugar cane. In Brazil, bioethanol prices are already below those for petroleum based transport fuels.

It is expected that production of second-generation liquid biofuels made from wood and other cellulosic feedstocks will be similarly competitive, both in terms of price and carbon emissions. Second-generation biofuel production is already under way in demonstration plants and commercially competitive production is expected to be in reach within the next decade. Most studies project that second-generation liquid biofuels from perennial crops and woody and agricultural residues could dramatically reduce life cycle greenhouse gas emissions relative to petroleum fuels. If technological developments make it more efficient and at least as economical to produce liquid biofuels from cellulosic material rather than from food crops, the result would be reduced competition with food production, an increase in energy efficiency and improved overall energy balance.

In the longer-term, biorefineries producing a range of products from wood pulp to transport fuels and specialized chemicals may become more widespread – especially in countries with sizeable wood processing industries, efficient business environments and effective policy implementation. Opportunities may also exist for export of transport fuels made from cellulosic materials to large high-paying markets. Associated increases in demand for wood are likely to push up prices until markets are able to re-equilibrate. Sawlog and pulp log prices, as well as wood panel prices are likely to be most affected and, indeed, prices are already responding in some markets.

With increasing demands on land from first-generation liquid biofuel development, pressure on forests is likely to increase around the world. The opportunity costs of forests are likely to be too high in many cases to prevent conversion to bioenergy crop production if markets develop in line with recent trajectories. Where measures to protect and sustainably manage forests are ineffective or not upheld, forest clearance may result. Extensive degraded lands available in many developing countries have also been suggested as areas for potential expansion of bioenergy plantations. To realize these benefits, however, the expansion of biofuel production will need to be accompanied by clear and well enforced land-use regulations, particularly in countries with tropical forests at risk of conversion to other land uses.

The attractiveness of markets, supported by bioenergy policies is already leading to forest clearance for the establishment of oil-palm and other crops used to produce liquid biofuels. Policy objectives related to climate change are unlikely to be reached as the amount of carbon released in land clearance may be much higher than can be recaptured by the bioenergy crop in many years. The situation is even more serious where peat lands have been cleared. In this context, it is important to note that bioenergy can only be considered renewable if biomass growth exceeds harvest, and carbon dioxide emitted during production, transportation and processing does not exceed that captured during growth. Carbon losses associated with conversion of land for bioenergy production should also be taken into account.

The extent to which wood energy will contribute to future energy production is likely to depend on: the competitiveness of wood-based energy in reaching the objectives of recent energy related policies; the costs and benefits of wood-energy-related systems in social, economic and environmental terms; and policy and institutional issues that provide the framework within which forestry acts. The potential of any bioenergy strategy will also be highly influenced by local context including: location relative to supply and demand; infrastructure, climate and soil; land and labour availability; and social and governance structures.

At present, wood energy is most competitive when produced as a by-product of the wood processing industry. Wood residues provide possibly the greatest immediate opportunity for bioenergy generation given their availability, relatively low-value and the proximity of production to existing forestry operations. Wood residues from felling and processing operations generally constitute more than half of the total biomass removed from forests.

In natural forests, up to 70 percent of total volume may be available for energy generation. Most of this material is made up of tree crowns and other rejected pieces that are left in the forest after harvesting operations. Wood residues from mills represent another, more easily accessible source of residues.

Forest plantations established solely for the purpose of energy production are becoming more common in some countries and it is likely that plantations with multiple end uses may provide logs for wood fuels as well as logs for other purposes as markets demand. Species not currently favoured by markets, areas of logged over forest, and trees outside forests provide addition potential sources of wood for energy outside the commonly marketed, and therefore, more highly priced categories of forest products.

Especially where human and financial resources are limited, bioenergy development should first explore opportunities based on already available biomass and proven technology. Integrating energy generation into industrial forest operations is a competitive way of reducing risks, increasing profitability and improving forest management. It also strengthens energy security and contributes to climate change mitigation and should thus be a priority area for exploration.

To ensure that sufficient cropland is available to produce food at affordable prices and to avoid loss of valuable habitats, it is imperative that bioenergy strategies are closely linked with, and integrated in, agriculture, forestry, poverty reduction and rural development strategies. Land-use planning and monitoring, as well as effective governance can play an important role in avoiding some of the social and environmental problems that are already being reported. All countries would benefit from better information about wood energy feedstocks, including biomass recovered from forest operations and trade of forest biomass.

Policies and programmes to support bioenergy development are still in their infancy. In relation to forestry the following issues need to be addressed first:

- sustainable mobilisation of wood resources in relation to legal and institutional constraints, forest ownership, data access, forestry infrastructure;
- supportive laws, regulations and policies; information dissemination to forest owners, entrepreneurs and other actors;
- efficiency gains through more intensive use of existing forest resources, of forest harvesting and processing residues, of woody biomass from trees outside forests, and of postconsumer recovered wood products;
- long-term expansion of the forest area and enhancements in the productivity of forest resources, for example, through silvicultural and genetic innovation;
- the potential use of marginal and degraded land to produce biomass for energy generation.

Transfer of advanced wood energy technologies to developing countries will be very important in relation to climate change objectives. The present situation represents a major opportunity and challenge for the forestry sector to find a new role in securing energy supply, mitigating climate change and supporting sustainable economic and environmental development.

1. Introduction

Energy plays a central role in the world economy and changes in energy costs have significant effects on economic growth, especially in oil importing developing countries. Currently, a major shift is underway in the sources from which energy is expected to be derived in coming years. The changes result from three primary concerns:

- high fossil fuel prices;
- perceived risks of fossil fuel dependence;
- increasing greenhouse gas emissions from fossil fuels.

Bioenergy offers the opportunity of reducing carbon dioxide emissions per unit energy production, reducing dependence on energy imports and, together with other alternative fuels, creating a cap on soaring oil prices. Depending on the effectiveness of policy and institutional frameworks, there is also an opportunity for countries to promote sustainable national and rural development through bioenergy expansion. Additionally, many countries have large forested areas, which if sustainably managed can produce large quantities of renewable fuels. A number of countries already have policies in place to encourage the use of wood for energy production.

Bioenergy is derived from a range of feedstocks and through a number of different processes. Some terms used to describe various types of bioenergy are explained in Box 1. A more complete list of definitions is provided in the Glossary. Traditionally, woodfuels, agricultural by-products and dung (referred to as "traditional biomass" in this paper) have been burned for cooking and heating purposes. Large-scale modern facilities, which convert wood and forest residues to power or both heat and power, are often constructed adjacent to wood processing facilities. This power source is considered renewable because new trees or other plants can replace those that have been converted to energy. It is important to note that bioenergy can only be considered renewable if biomass growth exceeds harvest, and carbon dioxide emitted during production, transportation and processing does not exceed that captured by the biomass that was harvested for energy.

There is great variation in the role of wood as a source of energy in different regions of the world. Many developing countries rely heavily on wood as a source of energy for heating and cooking, and wood resources are often threatened by loss of forest cover resulting from increasing population, agricultural expansion and unsustainable forest management practices. Industrialized countries and large rapidly growing developing countries consume a vast majority of the world's fossil fuels and are increasingly making use of wood energy at industrial scales. Some, but not all, have been able to stabilize or increase their forest area.

Recently, the potential of liquid biofuels to substitute for transport fuels has become a strong impetus for investment in the production of bioethanol and biodiesel

BOX 1
Bioenergy terminology

The term "bioenergy" refers to all types of energy derived from biofuels. Biofuels are fuels derived from matter of a biological origin, or biomass.

FAO categorizes biofuels according to the source of biomass used in production – forest, agriculture or municipal – and the state of the product. Thus, biofuels comprise woodfuels, agrofuels and municipal by-products and each of these groups is divided into solid, liquid and gaseous forms of fuels that can be used for heat or power generation. Taking woodfuels as an example, the following main groups are defined:

- solid woodfuels – fuelwood (wood in the rough, chips, sawdust and pellets) and charcoal;
- liquid woodfuels – black liquor (a by-product of the woodpulp industry) and ethanol, methanol and pyrolytic oil (from the thermochemical and biochemical breakdown of wood);
- gaseous woodfuels – pyrolitic gas (produced from the gasification of solid and liquid woodfuels).

The term "agrofuels" refers to biomass materials derived directly from fuel crops and agricultural, agro-industrial and animal by-products. Municipal biofuels include mostly waste products such as sewage sludge and landfill gas as well as municipal solid wastes.

In this paper, the term "biofuel" refers to all fuels of biological origin while the term "liquid biofuel" is used to denote fuels of biological origin that are liquids. This contrasts with the common use of the term biofuel in Europe to denote liquid fuels of biological origin that are used as energy sources for transport – bioethanol and biodiesel. This terminology is not followed here.

Source: FAO, 2004

from plant products. Liquid biofuels are currently manufactured predominantly from food crops including oil-palm, sugar cane, maize, rapeseed, soybeans, wheat and others. In general, first-generation bioethanol is produced from plant sugar or starch and biodiesel from plant oil. As such, the potential for competition between end uses exists, and many claims have been made that food prices have risen as a result of demand for these and other crops in energy production.

In the medium-term, it is expected that technology will become available for an economically competitive production of liquid biofuels from cellulosic material. Wood, agricultural residues and some grasses, such as *Panicum virgatum* and *Miscanthus sinensis*, are the most likely feedstocks that will be used. Because these feedstocks are not used as food sources and because they can grow in areas considered marginal for food production, increases in food prices may be less likely to result from their use.

In the near-term, there is a considerable likelihood that expansion of agricultural production for bioenergy will increase pressure on land and result in increased forest clearance. Although several current and emerging crops used for liquid biofuel production are suited to marginal lands, they often compete for land currently occupied by forest. Because forests store considerable amounts of carbon, replacement with bioenergy crops may result in a net loss of terrestrial carbon. At present, 17 percent of global carbon dioxide emissions are related to deforestation (IPCC, 2007).

As interest in bioenergy increases and possible system impacts are mapped out, a number of similar trade-offs have come to light. In recent research articles, arguments have been raised that down play the role of liquid biofuels in mitigating climate change. The key issue is the degree to which liquid biofuels actually reduce carbon dioxide emissions in comparison with fossil fuels. Because energy is used to grow, harvest, process and transport crops and biofuels, the net benefit may be small in some cases and even negative in others. Second-generation liquid biofuels do, however, offer greater potential. In contrast to current liquid-biofuel use, using wood from sustainable sources for heat and power generation, or for both heat and power production, is highly efficient both in terms of energy conversion and greenhouse gas emissions.

In coming years, global energy use is set to climb steeply and fossil fuels, despite their drawbacks, are likely to remain the most economically viable sources of energy. The extent to which energy sources are likely to change in the future depends, among other things, on energy prices and dependence on fossil fuel imports, the cost and mitigation potential of alternative energy sources and the degree of commitment to climate change mitigation. Political decisions related to agricultural and rural development subsidies will also play a very important role (Wolf, 2007). As the dynamics of energy use evolve in combination with climate change, the consequences for the world's forests will be profound. Demand for energy is clearly one of the most critical issues facing the forest sector in the twenty-first century. There are great challenges ahead. Correct policy decisions offer the opportunity to optimize economic, environmental and social benefits and to spread gains across society and over generations.

2. Energy supply and demand: trends and prospects

Energy demand is expected to increase considerably in the coming years as the result of population growth and economic development (EIA, 2007). Many people in the world are currently experiencing dramatic shifts in lifestyle as their economies make the transition from a subsistence to an industrial or service base. The largest increases in energy demand will take place in developing countries where the proportion of global energy consumption is expected to increase from 46 to 58 percent between 2004 and 2030 (EIA, 2007). Per capita consumption figures are, however, likely to remain well below those in Organisation for Economic Co-operation and Development (OECD) countries.

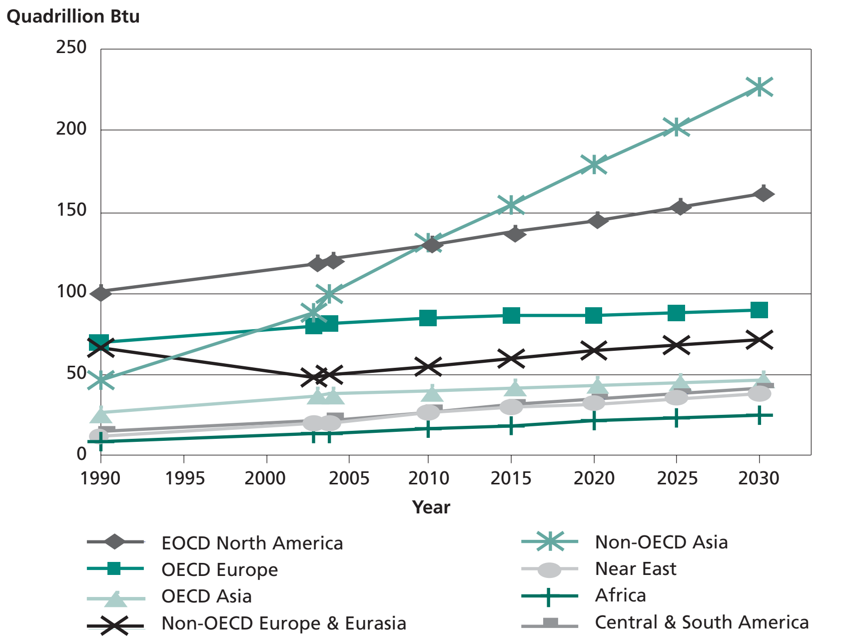
Energy consumption in developing countries is projected to grow at an average annual rate of 3 percent from 2004 to 2020. In industrialized countries, where national economies are mature and population growth is expected to be relatively low, the demand for energy is projected to grow at the lower rate of 0.9 percent per year, albeit from a much higher starting point. Energy consumption in developing regions is projected to surpass that in industrialized regions by 2010. About half of the increase in global energy demand by 2030 will be for power generation and one-fifth for transport needs – mostly in the form of petroleum-based fuels (EIA, 2007).

Much of the increase in energy demand will result from rapid economic growth in Asian economies, especially China and India. Energy demand in the developing countries of Asia is projected to grow at an average rate of 3.7 percent per year, far higher than any other region (Figure 1). Asia will more than double its energy consumption over the next 20 years, and is expected to account for around 65 percent of the total increase in energy demand for all developing countries. Although the energy consumption of developing countries in other regions is expected to grow at a slower pace than in Asia, rates are still expected to exceed the global average (Table 1). While all regions will play a role in future energy supply and demand, the enormous consumption increases projected in Asia make the region of key interest in future energy development.

The vast majority of the world's energy is generated from non-renewable sources, specifically oil, coal and gas (Figure 2). Just over 13 percent of global energy is derived from renewable sources, 10.6 percent of which from combustible renewables and renewable municipal waste. The remainder of renewable energy comes from hydro-, geothermal, solar, wind, and tidal and wave sources.

Projections of total global energy consumption show that between 2004 and 2030, fossil fuels will provide the bulk of the increase, with nuclear and other sources providing relatively minor contributions in absolute terms (Figure 3 and Table 1). In

FIGURE 1
Total marketed energy consumption for OECD and non-OECD countries, 1990–2030*



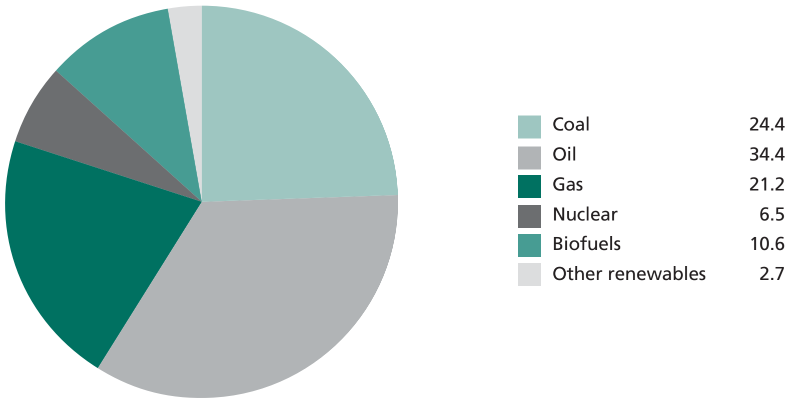
*Projections after 2004
Note: does not include traditional biomass
Source: EIA, 2007

TABLE 1
World total marketed energy consumption by region and fuel, 1990–2030 (quadrillion Btu)

Region/Source	Year					Growth
Region	**1990**	**2004**	**2010**	**2020**	**2030**	**% Annual growth 2004–2030**
OECD North America	100.8	120.9	130.3	145.1	161.6	1.1
OECD Europe	69.9	81.1	84.1	86.1	89.2	0.4
OECD Asia	26.6	37.8	39.9	43.9	47.2	0.9
Non-OECD Europe & Eurasia	67.2	49.7	54.7	64.4	71.5	1.4
Non-OECD Asia	47.5	99.9	131.0	178.8	227.6	3.2
Near East	11.3	21.1	26.3	32.6	38.2	2.3
Africa	9.5	13.7	16.9	21.2	24.9	2.3
Central & South America	14.5	22.5	27.7	34.8	41.4	2.4
Total OECD	**197.4**	**239.8**	**254.4**	**275.1**	**298.0**	**0.8**
Total Non-OECD	**150.0**	**206.9**	**256.6**	**331.9**	**403.5**	**2.6**
Source						
Oil	136.2	168.2	183.9	210.6	238.9	1.4
Natural Gas	75.2	103.4	120.6	147.0	170.4	1.9
Coal	89.4	114.5	136.4	167.2	199.1	2.2
Nuclear	20.4	27.5	29.8	35.7	39.7	1.4
Other	26.2	33.2	40.4	46.5	53.5	1.9
TOTAL WORLD	**347.3**	**446.7**	**511.1**	**607.0**	**701.6**	**1.8**

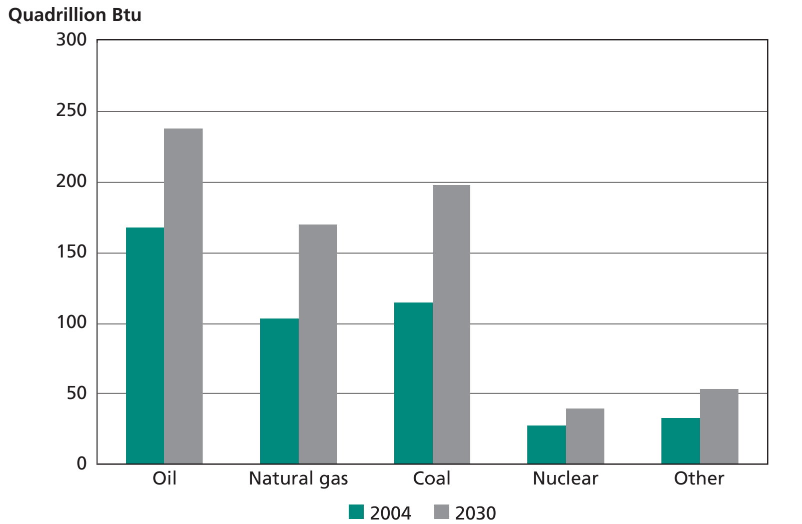
Note: does not include traditional biomass
Source: EIA, 2007

FIGURE 2
Fuel shares of world total primary energy supply in 2004 (%)



Source: IEA, 2007a

FIGURE 3
Total global marketed energy consumption by source in 2004 and projected for 2030



Note: does not include traditional biomass
Source: EIA, 2007

percentage terms, gas and coal are likely to show the greatest change with increases of 65 and 74 percent respectively. Oil consumption is expected to increase by 42 percent while nuclear and renewables, starting from a much lower baseline, are expected to increase by 44 and 61 percent respectively. The ultimate contributions from different sources will be highly dependent on policy directions. Projections should therefore be viewed primarily as a point of departure for further discussion.

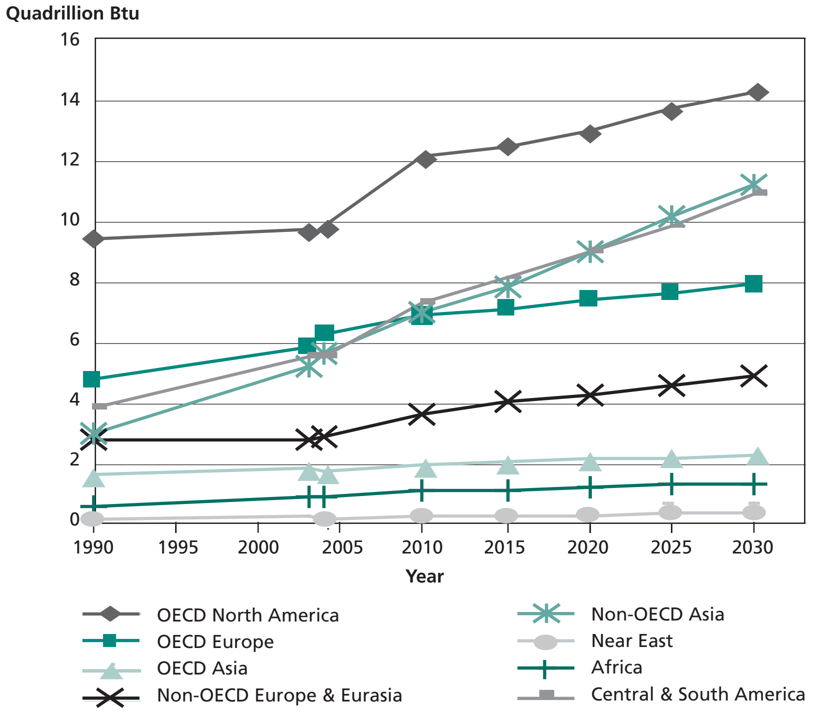
RENEWABLE ENERGY

Renewable energy consists of energy produced and/or derived from sources that can be renewed indefinitely, such as hydro-, solar and wind power, or sustainably produced, such as biomass. Notwithstanding the forecast dominance of fossil fuels, the use of renewable sources of energy is expected to expand. Based on United States Energy Information Administration (EIA) projections, marketed renewables will grow over the next decades at an annual rate of around 1.9 percent. The greatest absolute increases are expected in North America, Asian developing countries and Central and South America (Figure 4). Annual growth rates in consumption of renewables are expected to be highest in the Near East, Asian developing countries and Central and South America (Table 2). In Asian developing countries, the trend is driven more by increased energy consumption than a particular focus on renewables as in Central and South America.

In most of the world's regions, the proportion of energy from marketed renewable sources is expected to increase in the coming years (Figure 5). By far the greatest overall proportion of renewable energy consumption is in Central and South America, where economically competitive non-fossil fuel sources of energy are already well established

FIGURE 4

Marketed renewable energy consumption for OECD and non-OECD countries, 1990–2030*



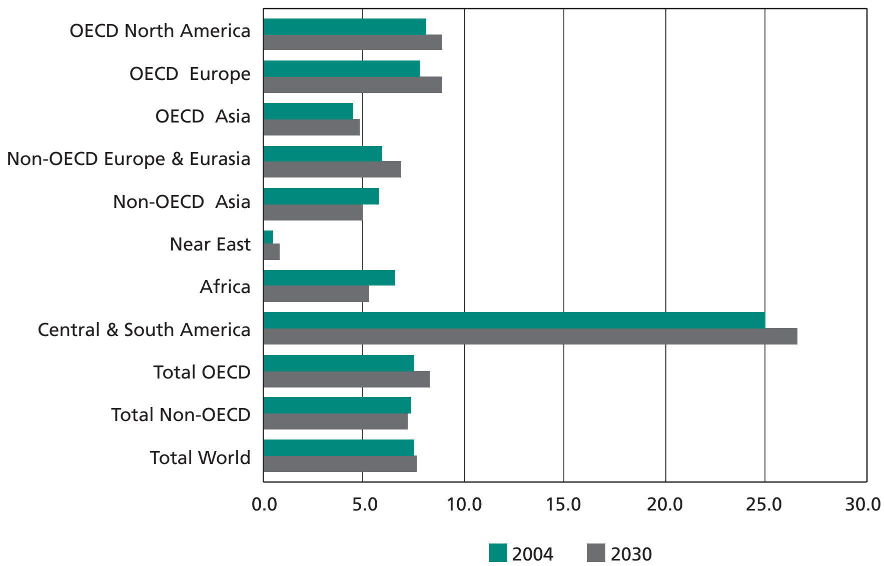
*Projections after 2004
Note: does not include traditional biomass
Source: EIA, 2007

TABLE 2
World consumption of hydroelectricity and other marketed renewable energy by region, 1990–2030 (quadrillion Btu)

Region	1990	2004	2010	2020	2030	% Annual growth 2004–2030
OECD North America	9.5	9.9	12.2	13.1	14.4	1.5
OECD Europe	4.8	6.3	6.9	7.5	8.0	0.9
OECD Asia	1.6	1.7	1.9	2.1	2.3	1.2
Non-OECD Europe & Eurasia	2.8	2.9	3.6	4.3	4.9	2.0
Non-OECD Asia	3.0	5.7	7.0	9.1	11.3	2.7
Near East	0.1	0.1	0.2	0.2	0.3	4.3
Africa	0.6	0.9	1.1	1.2	1.3	1.4
Central & South America	3.9	5.6	7.4	9.1	11.0	2.6
Total OECD	**15.9**	**17.9**	**21.1**	**22.7**	**24.7**	**1.2**
Total Non-OECD	**10.3**	**15.3**	**19.3**	**23.9**	**28.8**	**2.5**
TOTAL WORLD	**26.2**	**33.2**	**40.4**	**46.5**	**53.5**	**2.5**

Note: does not include traditional biomass
Source: EIA, 2007

FIGURE 5
Percentage of marketed renewable energy in total energy consumption for OECD and non-OECD countries in 2004 and projected for 2030



Note: does not include traditional biomass
Source: EIA, 2007

(Box 2). These figures do not take into account the recent long-term energy strategy of the European Union (EU), which proposes that by 2020, EU consumption of renewables will increase to 20 percent of total energy use; the proportion of biofuels used in transport will increase to 10 percent; and EU greenhouse gas emissions will be reduced to 20 percent below 1990 levels (European Union, 2007).

BOX 2

Biofuels for transport in Brazil

Worldwide, only about 1 percent of the consumption of transport fuels comes from liquid biofuels. Brazil is a notable exception to this average. During the first global oil crisis in 1975, Brazil launched a national biofuel programme leading to the large-scale production of ethanol from domestic sugar supplies. More than 90 percent of all cars produced and sold in Brazil are "flex", that is equipped with a motor that can run on ethanol, petrol or mixtures. Brazil has recently launched a global campaign to promote biofuels as a viable alternative to fossil fuels for transport.

In Brazil, biofuel from sugar cane sources is more competitive than petrol, when the oil price is above US$35 per barrel. Bioethanol from corn in the United States is, by comparison, competitive at an oil price of US$55 per barrel, and bioethanol in the European Union requires an oil price of US$75 to $100 per barrel to be competitive (Worldwatch Institute, 2007).

The success of biofuels in Brazil is largely a result of the high productivity of sugar cane and the suitability of the feedstock for efficient conversion to ethanol. Approximately 190 000 ha of sugar-cane plantations are established every year, mostly in the southern parts of the country (FAO, 2007c). Brazil is expected to continue to be the major biofuels exporter worldwide (Global Insight, 2007).

Higher fossil fuel prices and government policies and programmes in support of the development of alternative energy will be factors in the competitiveness of renewable energy sources. In spite of national and international efforts, however, forecasts do not show the global share of renewable energy increasing significantly. A minor expansion from 7.4 to 7.6 percent is all that is expected by 2030 (EIA, 2007).

The World Alternative Policy Scenario presented in the World Energy Outlook 2006 (IEA, 2006) shows how the global energy market could evolve if countries around the world were to adopt policies and measures currently under consideration for reducing carbon dioxide emissions and improving energy supply security (Table 3). In the scenario, the share of renewables in global energy consumption remains largely unchanged while the share of traditional biomass falls. Hydropower production will grow but its share will remain stable, while the shares of other renewables (including geothermal, solar and wind) will increase most rapidly, but from such a low base that they will remain the smallest component of renewable energy in 2030.

With the inclusion of traditional biomass, heating and cooking will remain the principal uses of renewable fuels over the next 25 years. The power sector, however, is expected to lead the global increase in renewable energy consumption (IEA, 2004). This sector accounted for a quarter of global renewable energy consumption in 2002, but its share is projected to rise to 38 percent by 2030. Currently, less than 1 percent of fuels used for transport are renewable. According to projections, this share will rise to 3 percent over the next 25 years. The overall impact of these changes on global energy consumption will be relatively small although the impact on deforestation and food security may be considerable.

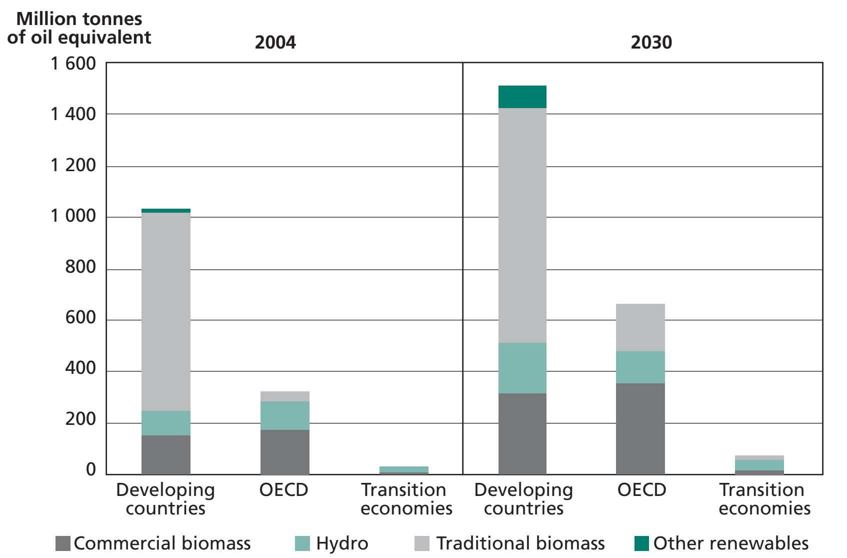
Renewable energy including traditional biomass makes up a greater proportion of total energy supplies in developing than in developed countries. About three-quarters of renewable energy are consumed in developing countries, where most renewable energy production is based on the use of traditional biomass and hydropower. Industrialized countries account for 23 percent of the total renewable energy consumed worldwide, and transition economies for 3 percent (Figure 6).

TABLE 3
Global increase in renewable energy

Energy source	2004	2030	Approximate increase (times)
Electricity generation (TWh)	**3 179**	**7 775**	**>2**
Hydropower	2 810	4 903	<2
Biomass	227	983	>4
Wind	82	1 440	18
Solar	4	238	60
Geothermal	56	185	>3
Tide and wave	<1	25	46
Biofuels (Mtoe)	15	147	10
Industry and buildings (Mtoe)	**272**	**539**	**2**
Commercial biomass	261	450	<2
Solar heat	6.6	64	10
Geothermal heat	4.4	25	6

Note: TWh = Terrawatt hour; Mtoe = Million tonnes of oil equivalent
Source: IEA, 2006; OECD/IEA 2006 cited in IEA, 2007a

FIGURE 6
World renewable energy consumption by region for 2002 and projected for 2030



Source: IEA, 2004

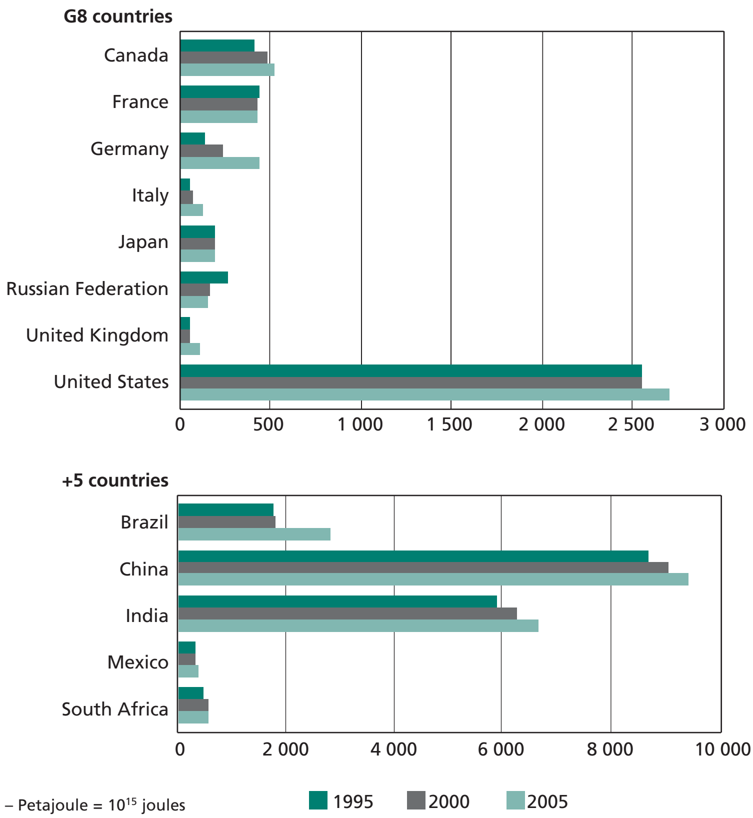
The two regions where renewable energy is the most significant are Africa and Latin America. In Africa, this is largely due to consumption of woodfuel for heating and cooking. In Latin America, it is due to the high use of renewables in Brazil, where 45 percent of all energy consumed is based on renewables – hydropower, wood, and sugar-cane ethanol.

Biofuel use is increasing in most of the G8 + 5 countries, which consume the largest amounts of energy in the world, with the notable exception of the Russian Federation where the availability of fossil fuels is increasing. In absolute terms, the United States, China and India consume by far the largest quantities of biofuels (Figure 7).

Figure 8 shows clearly the impact of government policies by comparing the relative use of bioenergy as a percentage of total energy consumption in the G8 + 5 countries between 1995 and 2005. Bioenergy increased as a percentage of total energy use between 2000 and 2005 in Germany, Italy, the United Kingdom, the United States and Brazil, all of which provided economic incentives for bioenergy consumption. However, the relative use of biofuels declined in China and India where high rates of economic growth outpaced the impacts of rising fossil fuel prices.

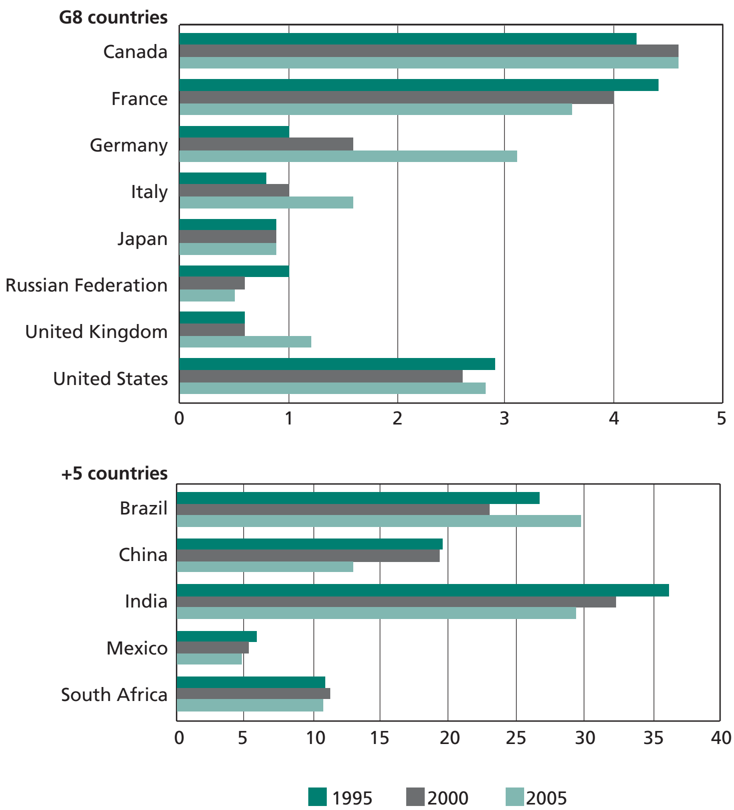
FIGURE 7

Total primary energy supply (TPES) from biofuels for G8+5 countries (PJ)



Note: PJ – Petajoule = 10^{15} joules
Source: IEA, 2007b

FIGURE 8
Percentage primary energy supply from bioenergy



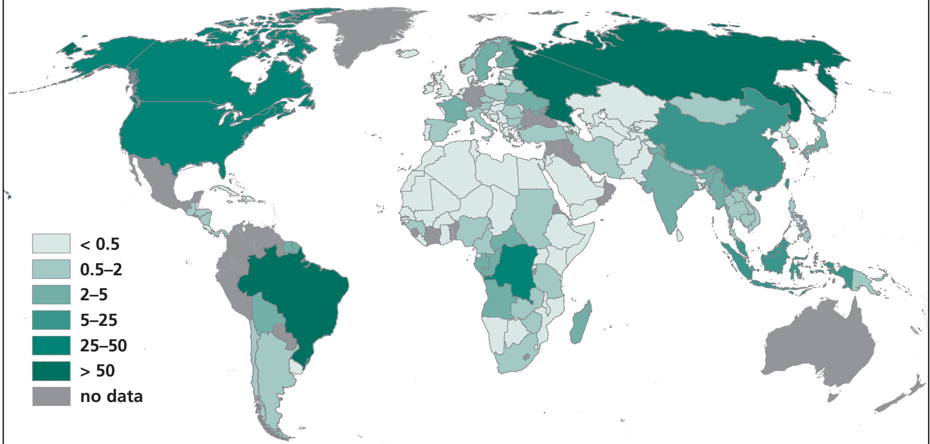
Source: IEA, 2007b

WOOD-BASED ENERGY

The availability of wood, and its potential as a biofuel to substitute for oil in the future, is unevenly distributed throughout the world (Figure 9). Global industrial roundwood production was about 1.7 billion cubic metres in 2005, compared with fuelwood production of approximately 1.8 billion cubic metres (FAO, 2007c). About 65 percent of global industrial roundwood was produced in industrialized countries, compared with only about 13 percent of fuelwood. The largest producers of fuelwood are India (306 million cubic metres), China (191 million cubic metres) and Brazil (138 million cubic metres). Production of fuelwood is significant in only a few industrialized countries including the United States, Mexico, Finland, Sweden and Austria among others. There are, however, problems with data availability, and household surveys of fuelwood-use have shown considerable consumption in several other industrialised countries (Steierer *et al.*, 2007).

The vast majority of fuelwood is still produced and consumed locally. Since fuelwood is mainly used in private households and is often traded informally, it

FIGURE 9
Total growing stock (billion m³)



Source: FAO, 2006c

is difficult to collect good country-level data. Many other caveats apply to the accuracy and availability of statistics on woodfuel (Box 3).

Historically, wood has been the most important source of bioenergy. Wood has been used for cooking and heating since the discovery of fire. In developing countries, it is also used in commercial applications such as fish drying, tobacco curing and brick baking. In developed countries, it is predominantly used for energy generation in the forest industry.

In recent years, wood energy has attracted attention as an environmentally friendly alternative to fossil energy, and investments have been made to improve efficiency, especially in relation to industrial applications, for heat and power generation. Changes in energy policy in several parts of the world have favoured the development of wood energy-based systems. New technologies are improving the economic feasibility of energy generation from wood, particularly in countries that are heavily forested and have well established wood processing industries.

In absolute terms, the largest OECD users of wood for industrial bioenergy by volume are the United States, Canada, Sweden and Finland. Most forest biomass used for energy in these countries is recovered from indirect sources, including black liquor from wood pulping and other wood residues (Steierer *et al.*, 2007). Industrial applications accounted for just over 50 percent of total bioenergy-use in each of these countries.

Fuelwood is the predominant form of wood energy in rural areas of most developing countries, while charcoal remains a significant energy source in many African, Asian and Latin American urban households. Developing countries account for almost 90 percent of the world's woodfuel (fuelwood and charcoal) consumption and wood is still the primary source of energy for cooking and heating in developing countries (Broadhead, Bahdon and Whiteman, 2001). Over

BOX 3

Impediments to accurate woodfuel information

Statistical information on woodfuel consumption has always been difficult to obtain. The main reasons are:

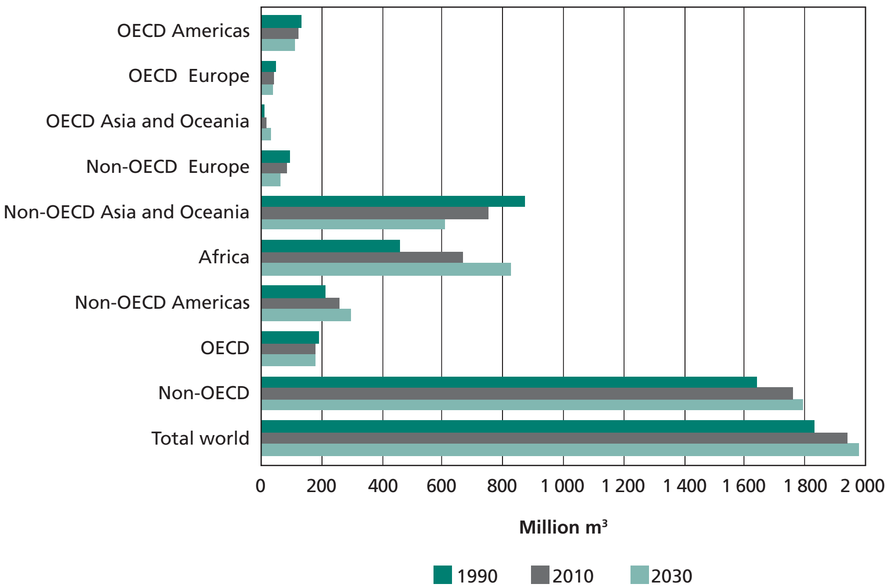
- High intensity surveys are necessary to collect accurate information since woodfuel production and consumption vary greatly across locations and at different times of the year.
- Woodfuel is mostly collected for the collector's own use and not sold in specific locations, such as markets, shops or factories, which would facilitate collection of information.
- Because of the low price of woodfuel in most countries, the sector is of little economic importance and investment in collection of statistics is therefore considered of little value.
- Many countries do not have the financial and human resources required to collect woodfuel information, especially as the countries where woodfuel is most important may also be the poorest.
- There is often poor coordination between institutions with an interest in the sector (e.g. government agencies dealing with agriculture, forestry, energy and rural development), and the benefit of information collection may be insufficient for any one agency.
- Many government forestry agencies focus their efforts on commercial wood production and neglect non-commercial forestry outputs.
- Information about woodfuel suffers from a lack of clear definitions, measurement conventions and conversion factors, which creates difficulties in comparing statistics across regions and over time.
- Because of widespread illegal logging, production may be under-declared and therefore the extent of wood residues available for energy use may be underestimated.

Source: Broadhead, Bahdon and Whiteman, 2001

the last 15 years global consumption of woodfuel has remained relatively stable, at between 1.8 and 1.9 billion cubic metres.

Figure 10 shows woodfuel consumption for OECD and non-OECD country groups between 1990 and 2030. The global trend indicates increasing consumption of woodfuel, largely a reflection of increasing consumption in Africa. Non-OECD countries in Asia and Oceania are, in contrast, showing a downward trend as rapid increases in income occur and urbanization takes place. Future consumption in OECD European countries is expected to be greater than shown in Figure 11 due to recent EU plans to increase the proportion of renewables in total energy use to 20 percent by 2020 (European Union, 2007).

FIGURE 10
Woodfuel consumption for OECD and non-OECD countries 1990, projections for 2010 and 2030



Source: Broadhead, Bahdon and Whiteman, 2001

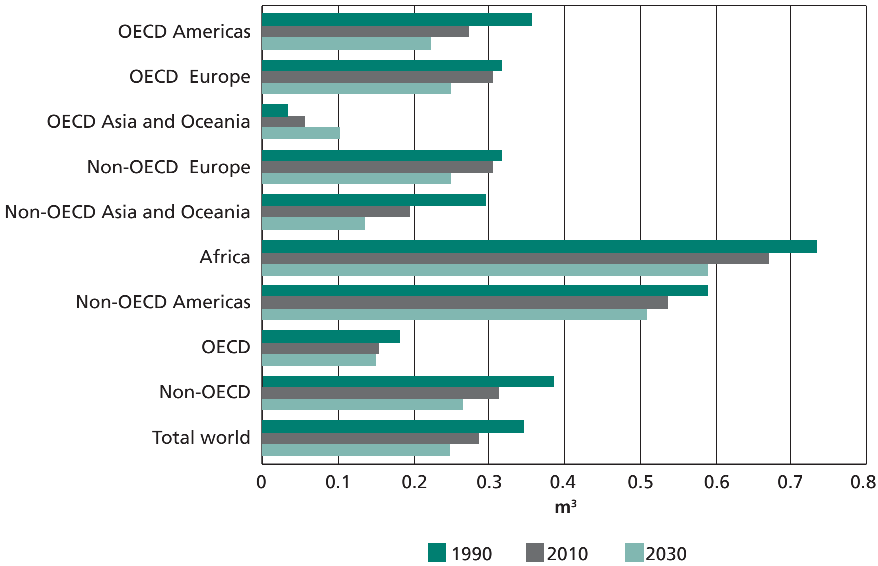
Recent surveys have also found that woodfuel consumption is considerably above previous estimates in several industrialised countries (Steierer *et al*., 2007). Figures shown for OECD countries are therefore probably towards the lower-end of the likely range.

Per capita woodfuel consumption (Figure 11) indicates differing trends in total consumption. In all regions of the world, except Asian OECD countries and Oceania, per capita consumption is decreasing as a result of rising incomes, urbanization, declining availability of wood sources and increasing availability of alternative sources of energy preferred to woodfuel. Despite this trend, total woodfuel consumption is increasing in African and in non-OECD countries in the Americas because of population growth.

Estimates of wood use in Africa show the vast majority of removals are for fuelwood and that the quantities consumed in industrial applications are relatively insignificant everywhere except in Southern Africa (Figure 12). Fuelwood use is increasing in all Africa's regions, although at a diminishing rate.

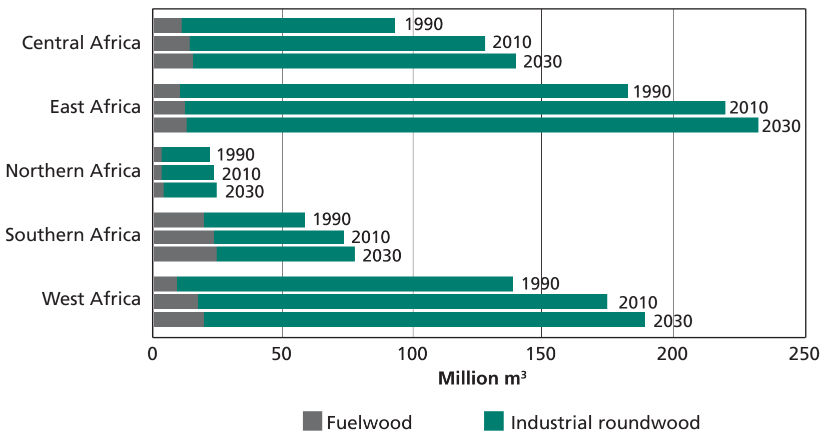
According to data collated by IEA (2006) the number of people using biomass resources as their primary fuel for cooking will increase (Table 4). Considerable increases are expected in Africa and in Asia outside of China. Overall, in the absence of new policies, the number of people relying on biomass will increase from 2.5 to 2.7 billion by 2030.

FIGURE 11
Per capita woodfuel consumption for OECD and non-OECD countries 1990, projections for 2010 and 2030



Source: Broadhead, Bahdon and Whiteman, 2001

FIGURE 12
Wood removals in Africa



Source: FAO, 2007b

Due to difficulties in collecting accurate information on woodfuel consumption, care is required in interpreting data. For example, recent increases in international energy prices have reduced the rate at which woodfuel users have been shifting to cleaner and more efficient fuels for cooking and heating (IEA, 2006).

TABLE 4
People using traditional biomass (millions)

Region/country	2004	2015	2030
Sub-Saharan Africa	575	627	720
North Africa	4	5	5
India	740	777	782
China	480	453	394
Indonesia	156	171	180
Rest of Asia	489	521	561
Brazil	23	26	27
Rest of Latin America	60	60	58
Total	**2 528**	**2 640**	**2 727**

Source: IEA, 2006

FUTURE ENERGY CHOICES – KEY ISSUES

Future energy choices will depend on a number of factors. The significance of different energy sources varies in relation to the key objectives in energy policy. Differences in carbon emissions are of importance to climate change, whereas supply location is of importance to energy dependence. Also of importance are the future price of fossil fuels and the magnitude of efforts to provide alternatives. The weight given to each of these factors and the degree to which different policy objectives compete will, to a large extent, determine future energy consumption.

Oil price

In early May 2008, oil was selling at US$126 per barrel following a steep rise from below US$20 per barrel in 1999 (figure 13). While IEA has projected that oil prices will be considerably lower than this level during most of the next 20 years, uncertainty over whether new production capacity will compensate for declining output at existing fields may mean an increase in oil prices prior to 2015 (IEA, 2007a).

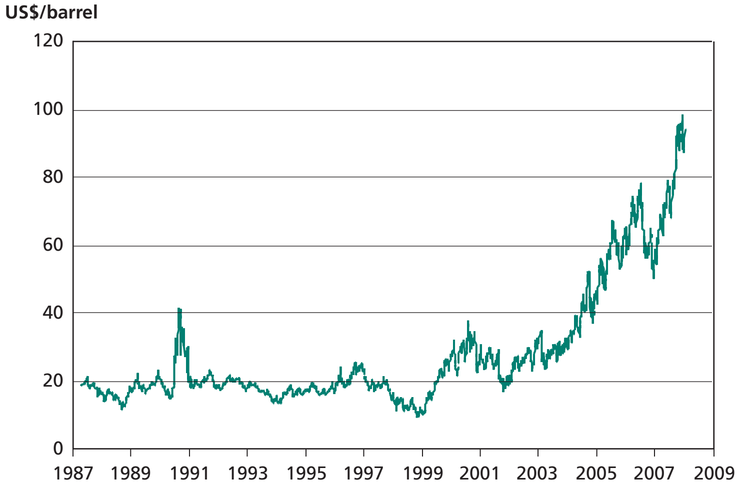
The price of oil and other fossil fuels is likely to considerably affect the adoption of renewables. Falling prices are less likely to encourage policy makers to promote renewables, although in developing countries, in particular, rising oil prices may also forestall investment in renewables by dampening economic growth.

In this respect, developing economies are especially sensitive to fluctuations in global energy supply and demand. The International Energy Agency estimates that a US$10 increase in the price of oil can reduce GDP growth by an average of 0.8 percent in Asia, and up to 1.6 percent in the region's poor highly indebted countries. The loss of GDP growth in sub-Saharan Africa can be even higher, in some countries reaching 3 percent (IEA, 2004). The effects of oil price on the development of renewables and the global distribution of consumption is likely to be convoluted and issues such as trade and technology transfer will be of great importance.

Greenhouse gas emissions

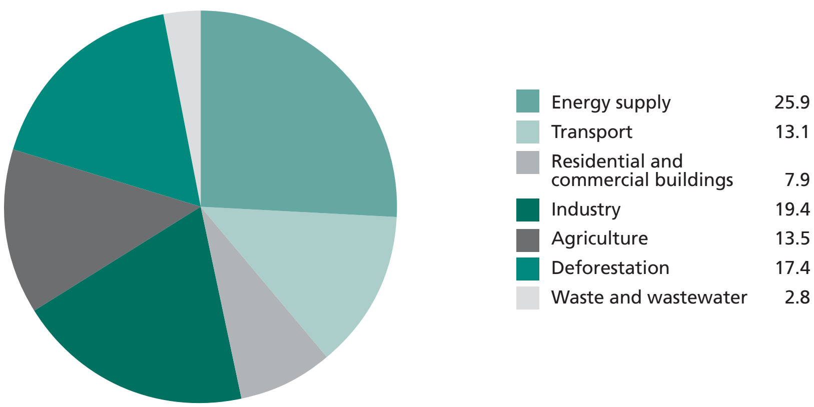
Global greenhouse gas emissions are dominated by energy production (Figure 14). Other sources, including land use change, forestry and agriculture account for around a third of emissions. Fossil fuel use is, however, the single largest human influence on climate, estimated to account for 56.6 of greenhouse gas emissions (IPCC, 2007). Transportation, although accounting for only one-eighth of emissions, has become a central focus in the bioenergy debate due to the carbon intensive nature of transportation, the high public profile of petroleum prices and dependency on producer nations.

FIGURE 13
Europe Brent Spot Price FOB, 1987–2008



Source: EIA, 2008

FIGURE 14
Global greenhouse gas emissions in 2000 by sector (%)



Source: IPCC, 2007

Despite the focus on oil and transportation in recent years, the significance of coal in future energy use and its role in climate change cannot be overlooked, especially if coal gasification processes become widely used in the production of transport fuels (Perley, 2008). Coal, by far the most polluting of the fossil fuels, is also of increasing importance – particularly in Asia where the highest energy demand increases are predicted. Of all fossil fuels, coal is the greatest contributor of climate change gases, surpassing oil in 2003. It provides a similar proportion of total world energy as gas, but emits twice the amount of carbon dioxide (IEA, 2006).

Since the supply of coal is not as restricted as oil, an increase in the share of energy supplied by coal seems inevitable, notwithstanding environmental legislation. Coal reserves are more widely dispersed than oil and gas. Large reserves of coal suitable for power generation are located in Australia, China, Colombia, India, Indonesia, the Russian Federation, South Africa and the United States. Growth projections for coal use point to the most dramatic increases occurring in Asia and the Pacific. China and India together are estimated to account for almost three-quarters of the increase in coal demand in developing countries, and two-thirds of the increase in world coal demand (IEA, 2003).

The considerable proportion of greenhouse gas emissions from deforestation – 17.4 percent annually – must also be taken into account. Efforts to ensure that production of bioenergy does not result in losses of terrestrial carbon through forest removal are critical if climate change objectives are to be achieved. Recent research has suggested that clearing of grassland or forest to produce biofuels may result in losses of carbon that will take centuries to recapture (Searchinger *et al.*, 2008; Fargione *et al.*, 2008).

Energy dependence

Dependence on energy imports is another key factor in determining the extent to which renewables and bioenergy are likely to be promoted. The degree of fuel import dependency in different regions of the world and the proportion of exports in total merchandise trade are given in Table 5. All regions outside the Near East have a high level of importation, and many regions export more than they import, indicating that some substitution could take place. Asia's imports considerably exceed exports. Europe and North America show smaller discrepancies between imports and exports, which are accounted for in part by current moves to promote biofuels.

TABLE 5
Share of fuels in total merchandise by region

Region	% exports	% imports
North America	7.1	11.7
Central and South America	20.2	15.6
Europe	5	8.5
Commonwealth of Independent States	43.9	9.8
Africa	51.9	10.2
Near East	73	4.3
Asia	5.1	14.7
World	**11.1**	**11.1**

Source: WTO, 2004

3. Bioenergy production

Many processes are available for producing bioenergy, from burning sticks and branches for cooking and heating to gasification of wood chips for transport fuel production. Energy producing systems may be compared in terms of energy efficiency, installation costs, carbon emissions, labour intensiveness or any range of costs and benefits. The appropriateness of different systems, however, will depend largely on existing structures and markets rather than isolated production assessments.

Recently, there has been much discussion of the presumed benefits of bioenergy in terms of carbon dioxide emissions. It should be noted, however, that bioenergy is only a renewable and sustainable form of energy under certain conditions (Perley, 2008). To maintain the carbon dioxide balance, biomass harvest must not exceed growth increment, and carbon dioxide emitted during production, transportation and processing must be taken into account. The conversion efficiency of the product should be considered together with its end use to limit the risk of policy failure.

The appropriateness of different bioenergy production systems in economic, environmental and social terms will depend to a large extent on national and local circumstances. In planning a bioenergy strategy, analysis of different options and their broad impacts should be carried out to ensure that policy objectives will be met.

SOLID WOODFUELS

While the use of wood for cooking and heating is as old as civilization, the efficiency of this energy source varies according to production systems. Open fires convert only about 5 percent of wood's potential energy. Traditional wood stoves increase this efficiency to about 36 percent, and charcoal-based systems are between 44 and 80 percent efficient, depending on the furnace design and charcoal production method. The modern wood pellet stove delivers about 80 percent efficiency for residential use (Mabee and Roy, 2001; Karlsson and Gustavsson, 2003).

A number of technologies are currently in use or under development for industrial-scale bioenergy production. These include power boilers for heat recovery, combined heat and power (CHP) systems for the production of both heat and electrical power, and gasifier systems for advanced energy recovery.

Steam-turbine power boilers designed to work primarily with bark can be added to sawmills as an alternative to beehive burners or other apparatus to dispose of waste. Heat from power boilers can generate steam, which can be used for electricity generation using turbines or to meet process requirements. Recovery boilers are used in a similar way in pulp and paper mills, to recycle black liquor and recover pulping chemicals, as well as to produce steam to drive the pulping process. The efficiency of a steam-turbine power boiler is generally about 40 percent (Karlsson and Gustavsson, 2003). The historically low cost of fossil fuels has not provided sufficient incentive for installing electrical generation capacity in mills.

In CHP facilities, steam produced is used to supply other industrial processes or support district heating grids for residential, institutional or industrial facilities. The recovery of both heat and power from the process can significantly increase the efficiency of operations. When the most recent technology is used, and flue-gas recovery and recycling incorporated, efficiency can rise to between 70 and 80 percent (Karlsson and Gustavsson, 2003).

The carbon efficiency of wood-based combined heat and power systems is generally high in relation to non-renewable energy sources and most other biofuels. Spitzer and Jungmeier (2006) found that heat production from a combined cycle power plant operating on wood chips produced only 60 g CO_2 equivalent for each kilowatt of energy produced. A similar plant using natural gas produced about 427 g.

New technologies that use gasification have been reported to be much more efficient for energy recovery in terms of electricity generation than traditional combustion in a power boiler. An integrated gasification combined cycle may increase efficiencies to about 47 percent and, theoretically, to 70 or 80 percent using CHP. Significant technical hurdles remain, however.

Gasification technology has been suggested as a means to provide small-scale power delivery suitable for villages and small-scale industry. Small-scale plants represent an appropriate technology, since they are cheaper, spare parts are more easily accessible, and repairs can be carried out on site (Knoef, 2000). In Cambodia, Abe *et al*. (2007) found that although biomass gasification provided cheaper power than diesel generators, consistent supply and barriers to growing wood were key constraints. The profitability of the small-scale plants set up as commercial enterprises has also been found to be marginal, and highly dependent on both energy prices and biomass input costs (Knoef, 2000). Wu *et al.* (2002) reach similar conclusions from work done in China and suggests that medium-scale plants may be more appropriate where financial considerations are of principal importance.

Wood pellet furnaces, using the most advanced technologies for energy conservation and recovery, have become an attractive technology option. Wood pellets are originally produced from wood waste (such as sawdust and shavings), rather than whole logs, and thus can be viewed as an integrated part of forest product manufacturing. The raw material is dried, mechanically fractioned to size, and extruded under intense pressure into pellets. Modern small-scale wood pellet furnaces are the most effective tool for bioenergy production on the small-scale.

LIQUID BIOFUELS

Biofuels include a range of liquid and gaseous fuels derived from biomass. "First-generation" biofuels are derived from food-crops and include sugar- and starch-based bioethanol and oilseed based biodiesel. "Second-generation" biofuels are derived from non-food crop agricultural and forestry products and make use of the lignin, cellulose and hemicellulose components of plant matter. Technology for processing the lignin component is still under development.

Recently, high oil prices have led to increased interest in liquid biofuels. Because of their lower price and more advanced state of development, those derived from food-crops are drawing the greatest attention. It is expected that in the medium-term, future technological advances will increase the competitiveness of second-generation biofuels. Currently, many governments are looking to biofuels as a way of reducing reliance on oil imports and reducing greenhouse gas emissions. For example, the Biofuels Initiative goals of the United States Department of Energy include making cellulosic ethanol costs competitive with gasoline by 2012, and replacing 30 percent of current levels of petrol consumption with biofuels by 2030 (UNECE/FAO, 2007).

First-generation liquid biofuels

First-generation liquid biofuels are manufactured from a range of crops that are relatively specific to geographic location. In temperate regions, rapeseed, corn and other cereals are used as biofuel feedstock, whereas in tropical regions, cane sugar, palm oil, and, to a lesser degree, soybeans and cassava are used. Sugar cane is not a widespread crop within OECD countries, among which only Australia and the United States rank as major producers. Sugar beet is, however, grown in many OECD countries and although production is primarily devoted to food products, this may change in the future.

The technologies for production of ethanol from sugars and starch have been refined and developed over the years. Brazil and the United States have made particular advances in these technologies, with Brazil focusing on sugar fermentation, and the United States on starch hydrolysis and fermentation. A number of countries in Asia and the Pacific have well-developed and expanding sugar-cane production systems, notably the Philippines, India, Pakistan and Thailand. An advantage of sugar cane use is that bagasse, the cellulosic component of the sugar-cane stalk, can be used to generate energy for production of bioethanol, thus increasing overall carbon and energy efficiency.

Production of oilseed crops is globally more widespread than sugar crop production. Oilseed crops are used in the production of biodiesel through a process known as transesterification. Production of oilseed crops, however, requires optimal soil and growing conditions. This may limit increases in production or result in the conversion of forest land that is suitable for cultivation of oilseed crops.

Europe has dominated the biodiesel industry to date, generating around 90 percent of global production using rapeseed oil as the main feedstock. Malaysia and Indonesia are currently the world's largest producers of palm oil. In 2006, Malaysia had an estimated 3.6 million hectares of oil-palm planted, while Indonesia had around 4.1 million hectares (FAO, 2007c). Estimates of current areas under palm oil cultivation vary considerably, however, and some sources report much higher figures than those collected by FAO (Butler, 2007a).

The development of biofuels and the palm oil industry is particularly relevant in Asia, given the steep projected increase in energy demand in the region. There are disputes over lands being converted to oil palm, with claims being made that expansion of oil-palm plantations in Malaysia and Indonesia has often been at the expense of recently logged over forest areas, valuable rainforests or carbon-storing peat swamps. In Southeast Asia, 27 percent of oil-palm plantations are located on drained peat lands (Hooijer *et al*., 2006). The related emissions contribute significantly to global greenhouse gasses.

Recently, the use of other oilseed plants, such as *Jatropha* spp., has been explored as a feedstock for biodiesel production. *Jatropha* is a genus of more than 100 species including shrubs and trees, originating in the Caribbean and now found throughout the tropics. The seeds of *Jatropha curcas* produce oil that is increasingly used for biodiesel production, particularly in the Philippines and India. The plant is hardy, grows well on marginal lands and can also be used to restore degraded lands. These characteristics suggest that *Jatropha curcas* production, if carefully managed, may be expanded without directly competing with natural forests or high-value agriculture lands used for food production.

Second-generation liquid biofuels

Second-generation technologies under development are expected to produce economically competitive liquid biofuels that can be used for transport from cellulosic feedstocks, including both agricultural residues and wood. It is anticipated that the technology for commercially competitive conversion of cellulose to liquid biofuels will be available within ten to fifteen years (Worldwatch Institute, 2007). Demonstration scale production is already under way (see www.iogen.ca), with bioethanol being the cellulosic liquid biofuel closest to commercialization. The United States Government is currently investing in small-scale cellulosic biorefineries (US Department of Energy, 2008).

Agricultural residues are likely to be among the lowest-cost liquid biofuel feedstocks. Bagasse and residues from the production of cereals, including maize, wheat, barley, rice and rye, are among the feedstocks that can be used to generate bioethanol. However, only about 15 percent of total residue production would be available for energy generation after accounting for needs related to soil conservation, livestock feed and factors such as seasonal variation (Bowyer and Stockmann, 2001). As bioenergy production increases, agricultural residues may become more important biofuel feedstocks, and their availability could increase through improved management practices.

Residues from the forest products industry and wood from forest plantations provide other potential sources of feedstock for commercial cellulosic biofuel production. Today, only a small proportion of liquid biofuels are forest-based, but the development of an economically viable process for producing cellulosic liquid biofuels could lead to the widespread use of forest biomass in the transport sector.

Two basic technologies are being developed to convert wood to liquid fuels and chemicals: biochemical conversions and thermochemical conversion (gasification or pyrolysis). In biochemical conversion, wood is treated using enzymes to release hemicellulose and cellulose as sugars. These sugars can then be further converted to ethanol or other products. The lignin residue is also converted to other products, or used to provide heat and power for the plant's operation or for sale.

In gasification, wood and bark are heated in the minimum presence of oxygen to produce a mixture of carbon monoxide and hydrogen, which, after clean-up, is referred to as synthesis gas (syngas). Syngas may be further converted to liquid transportation fuels. Pyrolysis is the process of treating wood at a lower temperature, in the absence or minimum presence of oxygen to convert wood to char, non-condensable gases and pyrolysis oils. Pyrolysis oil may be used directly for fuel or refined into fuel and chemicals.

Currently, biochemical conversion technologies require clean wood chips (without bark), which could draw on the same wood resources as pulp mills. Thermochemical conversion, however, can use a mix of wood and bark.

An interesting prospect is that of biorefineries, which are expected to produce not only heat and power, but also transportation fuels and industrial products. Modern pulp mills, which in some cases are net producers of heat and power, can be described as prototypes of biorefineries. The vision is that pulp mills will go from being large energy consumers and producers of only pulp and paper, to being producers of pulp and paper, as well as heat, electricity, transportation fuels and speciality chemicals. There is potential for adjusting the product mix to market situations, thus optimizing the profit made from a given amount of wood (UNECE/FAO, 2007).

It is probable that second-generation processes will be more profitable when integrated into existing manufacturing facilities, such as paper mills, that produce or have access to low-cost or by-product biomass (Global Insight, 2007). Cellulosic ethanol production is likely to be limited outside the United States, Europe, and Brazil due to the limited size of the expected markets and the availability of imports.

At present, the United States is among the most advanced countries in terms of cellulosic conversion. Support there is being given for the development of integrated forest biorefineries that would be added to existing pulp mills and produce renewable bioenergy and bio-products from forest and agricultural materials (UNECE/FAO, 2007). Current efforts are in three focal areas:

- seeking cost-effective processes to separate and extract selected components from wood prior to pulping for use in producing liquid fuels and chemicals;
- using gasification technologies to convert biomass, including forest and agricultural residues and black liquor, into a synthetic gas, which is subsequently converted into liquid fuels, power, chemicals and other high-value materials;
- enhancing forest productivity, including developing fast-growing biomass plantations designed to produce economic, high-quality feedstocks for bioenergy and bio-products.

The development of technologies for production of biofuels from cellulosic sources holds great promise for the use of wood in energy production. The fact that advanced technologies will be required, however, places constraints on the global availability of systems to convert wood and other cellulosic feedstocks into liquid fuels. The Institute for Agriculture and Trade Policy has warned that patent policy and the cost of patent royalties and licensing fees will influence the adoption of biofuels (IATP, 2007). In addition to the technological and economic issues, an understanding of patent policy on biomass and biofuels production is of crucial importance in understanding how biofuel technologies might contribute to sustainable development.

Countries and private companies considering the production of second-generation liquid biofuels from cellulosic biomass face an uncertain, if potentially lucrative, future. The development of technologies for the competitive production of liquid fuels from wood will require time and significant investment in research. Considerable investment is also needed for large-scale facilities, especially for gasification. It should be noted that the high oil prices in the early 1980s resulted in a number of gasification plants for the production of methanol from wood, particularly in a number of European countries. These, however, were eventually undercut by lower oil prices (Faaij, 2003). The risks associated with investment in second-generation liquid biofuels are relatively high; therefore most developing countries will probably explore other options fully before embarking on this venture.

4. The contribution of wood energy to future energy demand

The future of bioenergy and wood energy development is largely dependent on the effectiveness of policies and the consistency with which they are implemented. Abundant coal reserves are still available in areas of the world where economic and population growth rates are predicted to be highest. If high fossil fuel prices cease to exist as an incentive for biofuel development, only where policy is effectively implemented will demand increase. In many cases, policy support will therefore be necessary to encourage investment in bioenergy development – at least until price parity with fossil fuels is in sight. As such, export markets could become more important where domestic policies fail to encourage movement away from fossil fuels.

Widely differing systems of production and use of wood energy exist throughout the world, and there are likely to be a range of responses to the recent shifts in energy policy in various countries. Supply and demand of traditional biomass, liquid cellulosic biofuels, residues from the forest industry and other forms of wood energy will be affected differently by different factors across developed and developing countries.

Factors associated with climate change, energy efficiency and supply location will play a central role in wood energy production. In addition, an array of ecological, economic and social issues will come into play. In some areas and on some land types, trees may be more productive than agricultural crops and may not have as many negative environmental effects. Low labour availability could also favour forest over agricultural crops. Other factors may reduce demand on forests for energy production, for example, technological problems with liquid cellulosic biofuel production and transportation-related constraints. In general, the contribution of forestry to future energy production will be influenced by:

- the competitiveness of wood-based energy in achieving the objectives of recent energy related policies;
- the costs and benefits of wood-energy-related systems in social, economic and environmental terms;
- policies and institutions that provide the framework within which forestry acts.

Any bioenergy strategy will also be highly influenced by local context, including: location relative to supply and demand; infrastructure, climate and soil; land and labour availability; and social and governance structures. Because of these many factors, it is difficult to make general comparisons between agricultural and forestry sourced bioenergy (Perley, 2008).

The development of economically competitive technology for the production of liquid cellulosic biofuels will cause a major shift in the importance of wood energy. At that point, forest products will compete directly with agriculture for a share in the biofuels market. Forest products will also become a source for transport fuel, and where energy consumption is significantly affected by policy measures (e.g. EU, United States), large markets will open up to forest-derived energy from developing countries around the world.

In many parts of the world, significant expansion of plantations for bioenergy may be hampered by impediments to investment such as conflicting land claims, insecure land tenure, risk of expropriation and ineffective governance. Social issues that commonly occur when natural vegetation is replaced with commercially managed crops may also arise as a result of changes in property and land-use rights.

Where agricultural crops are favoured over trees, the contribution of forestry may be confined to efficiency gains in current uses and increasing the use of wood residues from existing forestry operations. Under these circumstances, the availability of wood for bioenergy production is likely to be less controlled by energy markets than by trends in roundwood production, extent of forest resources and demands that compete for wood residues.

Although the price of oil is high, developing countries need to assess the risks associated with investments in bioenergy very carefully. Many investments in biofuels made in the 1980s collapsed shortly after oil prices returned to their original levels (IBDF, 1979; Tomaselli, 1982). But the situation is again changing as new elements such as global warming have become more relevant.

Investments in bioenergy often depend on subsidies and new technology developments. Developing countries have limited finances and many priorities, so a full assessment of the risks and the identification of ways of maximizing the benefits from investments in bioenergy are fundamental. The Clean Development Mechanism (CDM) of the Kyoto Protocol offers incentives for establishing energy plantations and financing sustainable biofuel use. The Kyoto Protocol also facilitates technology transfer to developing countries.

WOODFUEL SOURCES

Wood energy produced with efficient technology is already competitive with fossil energy in many countries and can offer some of the highest levels of energy and carbon efficiency among bioenergy feedstocks, in particular when used for heat and power generation. Besides being economically attractive, wood energy is a strategic option for increased energy security, particularly in countries that have large forest areas and that depend on energy imports.

Sources of wood for energy production may be derived from a range of existing production systems. Wood residues provide the greatest immediate opportunity for energy generation given their availability, relatively low-value and the proximity of production to existing forestry operations. Plantations established solely for the purpose of energy production are becoming more common in some countries and it is likely that plantations with multiple end uses will contribute energy logs as well as logs for other purposes as markets demand. Logged over forest areas and species not currently favoured by markets are additional potential sources of wood for energy.

Wood residues

Many countries have no clear perception of the amount of biomass that can be collected from ongoing forest operations, and have never assessed the full potential of wood residues for energy generation. Table 6 compares wood residue availability for natural forest in the Amazon region and fast-growing pine plantations for two typical industrial operations in Brazil. The information shows that only a small portion of the tree is converted into market products. In natural forests, between 80 and 90 percent of total residue volume could be used for energy generation. Most of this material consists of tree crowns and other rejected pieces that are left in the forest after harvesting operations.

In developing countries, excess wood residues at mill sites are often left unused and may create environmental problems by affecting water and air quality. Producing energy from these residues can solve both energy and waste disposal problems. Residue combustion technology includes simple steam machines for small-scale power production and steam turbines for larger power plants (ITTO, 2005).

Theoretical analyses of energy supply from wood residues in developing countries suggest that there is considerable potential for energy generation (Tomaselli, 2007). In countries such as Cameroon, wood residues generated at mills alone are estimated to be sufficient to supply the total national electricity demand. If all the residues from forest operations were used for electricity generation, the country would be able to produce five times its current demand.

Wood residues from mills could also produce a significant portion of the electricity consumed in Gabon, Nigeria, Malaysia and Brazil. The potential contribution of wood residues to total electricity consumption in India, Thailand, Colombia and Peru is relatively small by comparison.

Wood residues from mills represent only a small portion of the total residues available. The volume of wood residues left from harvesting operations in tropical forests is three to six times that generated at mills. Efficient harvesting and transport technology methods could be used to collect this material and deliver

TABLE 6
Wood residues from forest industry operations in Brazil (% of total wood harvested)

Operation	Natural forest		Plantations	
	Product	Residue	Product	Residue
Harvesting	30–40	60-70	80-90	10-20
Primary and secondary processing	10-20	10-20	30-40	40-50
Total		**80-90**		**60-70**

Sources: ITTO, 2005; STCP Data Bank (adapted) it to power plants, in order to reduce costs, mitigate environmental impacts and produce power. Given that this is already done to a significant degree in most advanced industrialised countries, there is thought to be limited scope for increasing the energy use of residues there (Steierer *et al.,* 2007).

In many countries, the use of agricultural and forest residues could significantly reduce land requirements for biofuel production, thereby reducing the social and environmental impacts of energy crop plantations. In practice however, the wood that is reported as being available for industrial energy production often cannot be harvested economically. Furthermore, logging, agricultural expansion and other factors have reduced forest area all over the world. Wood residue supply can therefore be expected to decrease in coming years, despite high rates of plantation establishment.

Wood residues are necessary for maintaining soil and ecosystem health, and certain amounts should therefore remain on the ground. Logging residues are an important source of forest nutrients and help reduce the risk of soil erosion (UN-Energy, 2007). The potential impacts of increasing biomass recovery could include nutrient scarcity, loss of biodiversity and changes to ecosystem function.

Energy plantations

Energy crops are not a new innovation. Forest plantations dedicated to the production of wood for energy have existed in many countries for some time (NAS, 1980), though most of them are small, use poorly developed technology and generally focus on supplying fuelwood for local consumption.

In temperate zones, there are a number of fast growing tree species suitable for energy plantations, including *Acacia mangium*, *Gmelina arborea* and several *Eucalyptus*, *Salix* and *Populus* species (Perley, 2008). Tree growth rates are highly variable depending on management, species and location. In tropical countries, growth rates are highly dependent on water availability (Lugo, Brown, and Chapman, 1988). Soil fertility is also a factor. Short rotation forest crops demand higher nutrient status than other forests that occupy lands less in demand for agriculture.

Brazil is one of the few countries where the large-scale production of energy from wood has been explored for decades. Significant investments have been made in plantation forests, mostly of fast-growing *Eucalyptus* spp., dedicated to the production of wood for industrial charcoal to feed the steel industry. Brazil has also developed forest plantations to produce biomass for combustion and generation of heat and electricity for the food, beverage and other industries.

Clear and consistent policies, laws and best practice guidelines can help to balance the cultural, economic and environmental trade-offs caused by increased investment in forest plantations (FAO, 2007a). High-productivity plantations, efficient harvesting and good logistics are fundamental in producing biomass at costs that allow for competitively priced energy generation.

As a source for bioenergy, trees offer an advantage over many agricultural crops, which usually have to be harvested annually, increasing the risk of oversupply and market volatility (Perley, 2008). The harvest of trees and other perennial crops can be advanced or delayed according to price fluctuations. Products include several different end-uses such as energy production, pulp or panel manufacture and even sawlog production.

Countries considering the establishment of energy plantations should begin by creating conditions for efficient production of bioenergy from plantations. This includes the development of appropriate genetic material for local conditions and advanced technology for silviculture, plantation management, harvesting, transportation and energy conversion.

Some developing countries would need to invest in technological research and development for several years in order to turn wood energy plantations into an attractive business. While risks can be mitigated by using suitable species and high quality genetic material, countries and investors need to be aware that they are dealing with the uncertainties of long-term investments. One major risk outside the control of countries and investors is the fluctuations in energy and wood prices over time.

Changes in energy prices may render woodfuel plantations for energy unviable, and consequently of no market value. This is less of a risk for countries with developed forest industries that can adapt the biomass to other uses. For example, wood pulp and reconstituted wood panels industries use the same raw materials, reducing the risk of investment in energy crop plantations. Investors need to consider whether forest planting and management for biomass is compatible with the forest industries currently operating in developing countries, especially the less developed ones.

Lesser used species and secondary forests

Species of wood that are not used by the timber industry represent another opportunity. A recent study analysed the possibility of combining the harvesting of traditional species for the timber industry with less-known or less-used species for energy production (ITTO, 2005). Such an approach to energy generation could lead to increased revenue and improve sustainable forest management.

Another opportunity to produce biomass for energy generation is the management of secondary forests. In tropical regions, extensive areas of secondary forests exist. This type of forest has large volumes of biomass that cannot be used by traditional wood-processing industries, which represent a potential source for energy generation. Application of the International Tropical Timber Organization guidelines for managing secondary forests can promote the sustainable development of these forests for wood energy production (ITTO, 2002).

Future wood supply

Given that the value of wood for fuel has been low in comparison with other end uses, the future supply of wood for bioenergy production is likely to come from existing forestry operations. This may change if technology becomes available for the economically competitive production of energy from cellulosic materials as outlined in Section 3.

Mabee and Saddler (2007) reviewed a number of regional and global outlook studies on forest fibre availability to determine the renewable global supply of forest biomass for wood energy production. They concluded that increased demand for wood energy in industrialized countries will have a significant impact on the amount of available excess forest biomass, taking between 10 and 25 percent of the estimated global surplus. The global availability of fibre may not, however, cover demand in some regions and increased demand from wood processing industries may also compete for supply.

The technologies and systems used for creating wood energy are of great importance in analysing the future availability of forest biomass for bioenergy purposes. Improvements in the efficiency of utilizing woodfuel could provide significant amounts of wood energy worldwide. By instituting a best practices approach to energy recovery (i.e. using CHP with flue gas recovery, or high-efficiency wood pellet stoves), the amount of energy available through woodfuel increases dramatically and the resource may be extended significantly.

Increases in forest-based bioenergy use may have an impact on traditional processing industries. In some industrialized countries, removals of wood from the forest for bioenergy applications already account for at least half of industrial roundwood production (Steierer *et al.,* 2007; FAO, 2007b). In others, the amount of wood used for bioenergy purposes is still small compared with industrial roundwood harvest. When residue recovery and postconsumer waste are factored in, however, wood use for energy exceeds industrial roundwood production in several industrialized countries. Possible impacts of wood demand for bioenergy production on forest product prices are detailed in Box 4.

EMISSIONS AND ECONOMICS OF BIOFUELS

Most studies project that second-generation liquid biofuels from perennial crops and woody and agricultural residues could dramatically reduce life cycle greenhouse gas emissions relative to petroleum fuels. Some options hold the potential for net emission reductions that exceed 100 percent – meaning that more carbon would be sequestered during the production process than would be emitted as carbon dioxide during its life cycle – if fertilizer inputs are minimized and biomass or other renewable sources are used for process energy (see Worldwatch Institute, 2007).

Studies suggest that use of bioethanol produced from maize represents only a slight improvement in fossil fuel use efficiency over direct use of petroleum, while bioethanol produced from wood can improve energy efficiency by up to four times (NRDC, 2006). Estimates put greenhouse gas emissions for biomass-based second-generation fuels at 75 to 85 percent below those of petroleum motor fuels, because of less-intensive farming and the assumption that the unfermentable portion of the plant is used as the processing fuel (Global Insight, 2007). Thus, if technological developments make it more efficient and at least as economical to produce liquid biofuels from cellulosic material rather than from food crops, the result would be reduced competition with food production, an increase in energy

BOX 4

Forest product prices

In European countries, wood prices have been declining for both roundwood and pulpwood in real terms (UNECE, 2007; Hillring, 1997). The long-term global trend is more difficult to determine, owing to currency conversions, the impacts of national inflation rates, national tax regimes and data availability. Global estimates of the future forest products market predict that the real prices of industrial roundwood, sawnwood and wood-based panels will change little before 2010, with those of newsprint, printing and writing paper decreasing slightly (FAO, 1997; Trømborg, Buongiorno and Solberg, 2000). However, over the past few years, real prices of forest products have been rising around the world.

Recent studies noted that prices for softwood sawlogs increased in most regions of North America and Europe in 2005/2006 (UNECE/FAO, 2006; 2007). Higher transportation costs and incentives for bioenergy production were cited as major reasons for these increases. Pulpwood prices have also increased in these regions, again probably owing to increasing transportation costs but also an improved pulp market. Prices for sawnwood and pulpwood are predicted to continue to rise over the next few years (UNECE/FAO, 2006).

Given existing trends in wood prices, several observations can be made.

- Even with rising wood value, the forest industry is experiencing lower returns today than in previous years and this is likely to act as a barrier to reinvestment or to new companies entering the arena.
- The present price of wood, which is low compared with historical data, may act as an incentive to use wood in relatively low-value applications such as bioenergy.
- As bioenergy opportunities are explored, increased competition for wood fibre should support the recent trend towards higher wood prices. As wood prices rise, development of bioenergy opportunities may slow down over the medium- to long-term.
- Government policies can have a significant impact on wood prices. Subsidies for investments in renewable energy, tax incentives, and tariffs are all having an impact on wood prices, especially in industrialized countries.

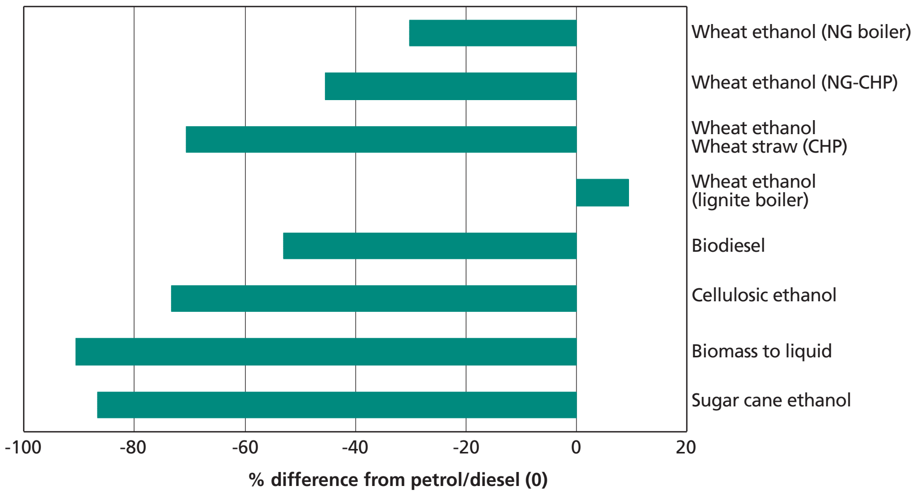
At present, it is expected that high demand for wood-based biofuel feedstocks will result in price increases for forest products. Pulp mills and panel manufacturers are in most direct competition with bioenergy applications for wood supplies, and in the short-term it is likely that consumers will face higher prices for some products (UNECE/FAO, 2007).

efficiency and improved overall energy balance. This could result in incentives to expand forest plantations.

Compared to gasoline or diesel, greenhouse gas emissions are lowest for biomass to liquid processes (i.e. gasification/pyrolysis processes that can utilize the whole plant). Sugar cane is similarly placed and cellulosic ethanol reduces emissions by over 75 percent. Ethanol sourced from wheat returns poor emission reductions unless the wheat straw is also used in CHP processes (Figure 15).

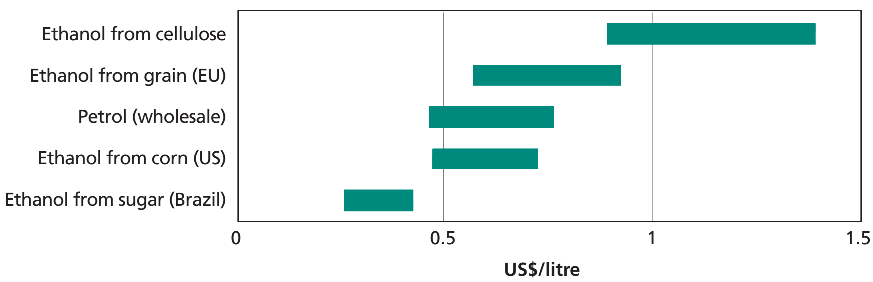
Sugar cane is the most economically attractive agricultural feedstock for liquid biofuel, while maize and other cereal and oilseed crops from the Northern Hemisphere are less competitive under market conditions (Figure 16). While the present costs of producing ethanol from cellulose are higher than those from cereal feedstocks, the potential for reducing production costs in the future appears to be much greater for cellulosic ethanol. By 2030 parity with ethanol from sugar cane may be possible (IEA, 2006).

FIGURE 15
Comparison of greenhouse gas emissions from biofuels derived from various sources



Note: CHP – Combined heat and power; NG – Natural gas
Source: Global Insight, 2007

FIGURE 16
Competitiveness of biofuels by feedstock



Source: see Worldwatch Institute, 2007

The development of an economically viable process for producing cellulosic liquid biofuels could lead to the widespread use of forest biomass in the transport sector. As most of the growth in demand for liquid biofuel is expected in developed countries, the scope for trade is the main factor affecting development plans in the majority of developing countries.

Feedstocks and processes that do not produce significant net energy gains are less likely to be supported by markets, although it is possible that other objectives may perpetuate their production (Wolf, 2007). It is unlikely that crops grown specifically for the production of cellulosic biofuels will be developed in significant quantities as technology gains and bioethanol prices are unlikely to favour production over alternative crops. Similarly, it is not expected that stand-alone second-generation bioethanol and biodiesel plants will be profitable in the coming decades (Global Insight, 2007). The competitiveness of different feedstocks is related to the net energy efficiency associated with production and processing of different crops (Box 5).

BOX 5

Energy efficiency and bioenergy production

Energy consumption in bioenergy production is important for two reasons. Firstly, to be sustainable, the amount of energy gained in growing and utilizing an energy crop must exceed that used in producing the crop. Secondly, the types of fuel used for the energy inputs and their greenhouse gas emissions must be taken into account where climate change goals are targeted through bioenergy use.

Energy use is dependent on a number of factors. Agriculture requires energy inputs at many different stages, including for powering farm machinery, irrigation and water management and transporting products. Large amounts of energy are also consumed in activities associated with agriculture, such as fertilizer and pesticide manufacturing and processing, and distribution of agricultural products. This is especially the case in modern high-input farming systems.

Agriculture in industrialized countries is generally much more energy intensive than in developing countries, although as they move to more advanced cultivation practices, energy inputs tend to increase. In many cases, energy inputs are likely to be from fossil fuels. For this reason, the production and use of bioenergy resources only marginally reduces carbon emissions in comparison with fossil fuel use.

The major advantage of forests and trees as a source of biomass is their lower energy inputs and their ability to grow on sites with lower fertility than those required for agriculture. There are, however, major constraints to capitalizing on these advantages including the timely emergence of second-generation technologies, the future supply of wood and the infrastructure necessary for economic viability (Perley, 2008).

5. Implications of increased use of bioenergy

There is a growing perception that bioenergy offers a range of advantages over other energy sources. These include increased rural income and reduced levels of poverty in developing countries, restoration of unproductive and degraded lands and promotion of economic development. By contributing to increased energy security, bioenergy also has strategic implications, particularly for oil importing countries. Finally, it has the potential to help reduce greenhouse gas emissions, which are a global concern.

There are, however, challenges to be overcome before the full potential of bioenergy can be realized. A number of problems associated with biofuel production, especially regarding large-scale operations, have been highlighted. In order to minimize bioenergy development strategy risks, it is important to fully analyse the different aspects of bioenergy and wood energy development:

- rural development, equity and poverty reduction;
- land and forest management, and biodiversity;
- food and forest product prices;
- greenhouse gas emissions and air quality;
- water availability;
- energy prices and energy dependence.

Bioenergy development entails both benefits and negative effects (Box 6). Given the range of interactions, the potential benefits and costs of investments in bioenergy should be assessed on a case-by-case or country-by-country basis.

There are many factors involved in increasing production of energy from biomass. Crop type and productivity are among the most important. In a 2004 study based on IEA data, different agrofuels were compared in terms of arable land requirements for a given amount of energy production. The results showed that soybean requires almost 12 times as much arable land as sugar cane. Other potential liquid biofuel sources fall somewhere between these two extremes. Corn, for example, requires twice as much land as sugar cane, while oil-palm requires about 30 percent more land.

Even more striking, is the answer to the question: "How much arable land would be required to replace 25 percent of the transportation energy from fossil fuels with energy from liquid biofuels?" The answer is 430 million hectares for sugar cane – 17 percent of the world's arable land – and 5 billion hectares for soybean – 200 percent of the world's arable land (Fresco, 2006). It is therefore not realistic to conceive of biofuels as totally replacing fossil fuels. Biofuels need to be viewed as one potential source of energy to be used in combination with others.

BOX 6

Potential benefits and negative effects of bioenergy development

Potential benefits

- Diversification of agricultural output
- Stimulation of rural economic development and contribution to poverty reduction
- Increase in food prices and higher income for farmers
- Development of infrastructure and employment in rural areas
- Lower greenhouse gas emissions
- Increased investment in land rehabilitation
- New revenues generated from the use of wood and agricultural residues, and from carbon credits
- Reduction in energy dependence and diversification of domestic energy supply, especially in rural areas
- Access to affordable and clean energy for small and medium-sized rural enterprises

Potential negative impacts

- Reduced local food availability if energy crop plantations replace subsistence farmland
- Increased food prices for consumers
- Demand for land for energy crops may increase deforestation, reduce biodiversity and increase greenhouse gas emissions
- Increased number of pollutants
- Modifications to requirements for vehicles and fuel infrastructures
- Higher fuel production costs
- Increased wood removals leading to the degradation of forest ecosystems
- Displacement of small farmers and concentration of land tenure and incomes
- Reduced soil quality and fertility from intensive cultivation of bioenergy crops
- Distortion of subsidies on other sectors and creation of inequities across countries

Sources: FAO, 2000; UN-Energy, 2007; Perley, 2008

POVERTY, EMPLOYMENT AND PRICES

A number of studies have reported that biomass production for bioenergy will offer developing countries new income sources, thereby reducing poverty and enhancing food security. There are, however, many variables which determine whether the expansion of bioenergy has a net positive or a net negative impact on livelihoods. When small-scale farmers have the opportunity to produce biomass independently or through outgrower schemes, there may be net benefits. But there is a history of disputes. In Indonesia, the establishment of large palm oil plantations has been associated with alleged land grabbing and human rights abuses (Aglionby, 2008).

The extent of employment opportunities resulting from bioenergy development is dependent on the crop and system of production. The harvesting of crops such as *Jatropha curcas* is labour intensive and can generate jobs and incomes for rural people. On the other hand, the harvesting of bioenergy crops such as sugar cane do not use much labour and provide relatively few jobs for the rural poor. The significance of liquid biofuels in relation to employment has therefore been questioned (Biofuelwatch, 2007). It is likely that production of bioenergy will provide greater opportunity for employment than fossil fuel import, especially where import levels are high. The scale and nature of production systems are however, crucially important to employment generation.

Bioenergy developments have the potential of making energy available to rural populations with limited access to other energy sources, and this can promote economic development. The living conditions of poor households would be improved if bioenergy development led to a more efficient and sustainable use of traditional biomass (UN-Energy, 2007).

Social conflicts can be provoked by the introduction of large energy plantations supplying centralized conversion facilities. Conversion facilities should be located close to biofuel production sites to reduce transport costs and increase economic viability. It is possible that such arrangements could result in increased concentration of landownership and displacement of traditional farmers. With effective local planning, however, structures involving farmers as outgrowers can be developed, resulting in opportunities for smallholder investment.

Competition for land and agricultural products may increase food prices but could also have the effect of improving farmer income. Those producing the greatest surpluses would benefit, while net buyers would suffer more. The distribution of costs and benefits will depend on local circumstances, although the net effect on food security of increasing food prices may be negative in many cases. The greatest impact may be on the urban poor who do not have access to land to capture benefits from increased agricultural prices.

If prices of liquid biofuel crops rise significantly, farmers will tend to convert food croplands to energy crops. In the short-term, this could reduce food supply, and food prices would increase. However, farmers shift cultivation quite frequently, and crop decisions are based mainly on market prices and profitability. Higher food prices would increase the incentive to use land for food crops, so the market would act to restore the supply–demand balance. However, it must be stressed that an increase in food prices, even if only transitory, would affect the poor – especially in developing countries (Box 7).

LAND AND ENVIRONMENT

Land is a key factor in the production of bioenergy resources, and its availability varies among and within regions and countries. Extensive establishment of energy plantations may place limits on the availability of land for producing food and as a result, food security is a concern for some countries – particularly those with limited land resources and high populations.

Recent studies have shown that although significant global reserves of potential cropland exist, predictions for population growth and land-use competition

BOX 7

Food prices and bioenergy

Rosegrant *et al.* (2005, 2006) studied potential impacts of the growing demand for energy on real world food prices. They examined three cases within an aggressive liquid biofuel growth scenario, which assumed that total biofuel consumption would rise between two- and tenfold in specific countries or regions around the world, including China, India, Brazil, the United States and the European Union, and presuming that oil prices would stay high in real terms. The three cases were:

- continued focus on cereal-based liquid biofuels;
- a shift to wood-based liquid biofuels;
- increased use of cellulosic biofuels combined with improvements in agricultural practices.

The authors estimated that in the first case, real food prices would rise significantly by 2020 (see table). In the second, offsetting new development with wood-based fuels could reduce these increases somewhat. Combining cellulosic biofuels with agricultural improvements could result in the lowest possible price increases. Each of these cases suggests higher real crop prices in the future.

Each of the three cases would entail higher average prices in the global food marketplace, although changes at the country level would vary. These results are confirmed by other models, notably an analysis by Schmidhuber (FAO, 2006a), which found that the extra demand for biofuel feedstocks has resulted in increased global agricultural commodity prices.

An increase in food prices would have an impact on food security, particularly in countries where food is scarce owing to poor growing conditions or other environmental factors. A price increase for food commodities would also increase incomes in rural areas, potentially reducing poverty. Increasing the proportion of wood-based biofuels could help decrease the expected rise in food prices, but some cost increases must still be expected. It should be noted that, historically, real prices for food and agriculture have been declining, and a departure from this trend to meet biofuel demand may not be permanent (FAO, 2006a).

Expected rises in commodity food prices in three cases under an aggressive biofuels growth scenario (percent increase, 2005 to 2020)

Commodity	Continued focus on cereal-based biofuels	Shift to wood-based biofuels	Wood-based biofuels + agricultural improvements
Cassava	135	89	54
Sugar beet	25	14	10
Sugar cane	66	49	43
Oilseeds	76	45	43
Maize	41	29	23
Wheat	30	21	16

Source: Rosegrant *et al.*, 2006

suggest that reserves are not well distributed in relation to future demand. For example, some Asian countries with high populations appear to have no, or very limited, land available for bioenergy production (Risø, 2003).

In heavily populated Asian countries, however, agroforestry, the use of agricultural and forest wastes and efficient energy conversion technologies could provide significant amounts of bioenergy. Latin America, much of Africa and some forest-rich countries in Asia have large areas that could potentially be turned over to biomass production. Biodiversity is, however, threatened when large-scale monocultures are grown for energy purposes, even when non-forest land is used. The loss of pastoral lifestyles associated with shrinking grasslands, and the loss of feed production for domestic and wild herbivores on these lands, could also have significant negative economic and social impacts (UN-Energy, 2007).

In many developing countries, extensive degraded lands are being considered for expansion of bioenergy plantations. India, for example, is focusing on 63 million hectares classified as wasteland. They estimate that 40 million hectares are suitable for cultivating oil-bearing plants (Prasad, 2007). The planting of trees or other energy crops in such areas has been suggested as a way to reduce erosion, restore ecosystems, regulate water flows and provide shelter and protection to communities and to agricultural lands (Risø, 2003). To realize such benefits, however, the expansion of biofuel production will need to be accompanied by clear and well enforced land-use regulations, particularly in countries with tropical forests at risk of conversion to other land-uses (Worldwatch Institute, 2007).

There has been resistance to agrofuel projects because of the risks and potential conflicts they pose. In Uganda, for example, the public reacted negatively when the government granted a permit to a company to exploit the Mabira forests for planting sugar cane for agrofuels. Similar reactions to agrofuel projects have also been reported in Ghana and South Africa (GRAIN, 2007).

Forests in several countries have been replaced by crops intended to produce biofuels and this trend could accelerate if there are large increases in the demand for biofuels and bioenergy in general. The dynamics could change dramatically, however, if woody biomass becomes the biofuel feedstock of choice, and a future in which forests threaten farmland, rather than the opposite may be possible.

To ensure that sufficient cropland is available to produce food at affordable prices and to avoid loss of valuable habitats, it is imperative that land-use planning and monitoring be considered in bioenergy strategies. Possible scenarios for liquid biofuel development are outlined in Box 8 together with their likely impacts.

Potential negative environmental impacts related to large-scale increases in forest and bioenergy plantations include reduced soil fertility, soil erosion and increased water use. Intensive cultivation increases and concentrates water consumption, and in many countries, water is an increasingly scarce resource. Some agrofuel crops consume large quantities of water. In March 2006, the International Water Management Institute issued a report warning that the rush for liquid biofuels could worsen the water crisis in some countries. For example, in China and India where water resources are scarce, a large share of agrofuel

BOX 8

Scenarios for liquid biofuel development

The large-scale production of bioenergy requires extensive land areas, and there are concerns that first-generation liquid biofuel crops could affect food security and forest cover. To deal satisfactorily with land-use issues and their implications on forests, liquid biofuel production could be expanded under one or a combination of the following scenarios:

- **Turning degraded lands and/or lands currently dedicated to food crops over to bioenergy production (including wood energy).** This approach would not be expected to impact upon forests although it could affect food security, especially in the case of large-scale operations, unless productivity is increased and/or synergies between food and energy production are found.
- **Introducing liquid biofuel crops into forested areas.** This would result in deforestation and impact on biodiversity and other forest goods and services, and would increase greenhouse gas emissions. Wood-based industries could face reductions in raw material supplies, and the demand for construction materials and other wood products may be reduced. Wood availability for energy production may increase in the short-term.
- **Diverting wood produced from existing forests to energy production.** This would have an impact on income and management of natural forests and plantations and would increase competition for resources among wood users. Wood available to the forest industry could decline in the short-term and the costs of products may increase.
- **Increasing efficiency of wood use by optimizing processing and using wood residues and recovered wood to produce bioenergy.** Significant amounts of energy could be generated and negative impacts on forestry and agriculture would be minimized.

crop production depends on irrigation (GRAIN, 2007). This can reduce the water resources for food crops and have impacts on food security. Though, these impacts can be mitigated through good land-use planning and responsible management (FAO, 2006b).

There is also concern about an increase in air pollution if biomass combustion increases (WHO, 2006). In particular, wood combustion in installations with insufficient filters or incomplete combustion releases fine particulates that pose a health hazard. Some countries have burning device standards, but these may be compromised by low fuel quality (e.g. wet wood) and ineffective burning techniques. As there are major consequences to increased biomass combustion, many of which are interlinked, a holistic approach is necessary when setting targets and making policies to combat climate change (UNECE/FAO, 2007). Valuable time and effort is also devoted to fuel collection rather than more profitable pursuits and for these reasons the United Nations Millennium Project has set a goal of halving the number of households using traditional biomass for cooking by 2015.

Forest clearance

With increasing demands on land from first-generation liquid biofuel development, pressure on forests is likely to increase around the world. In many cases, the opportunity costs will be too high to prevent conversion of forests to the economically attractive land-uses that will emerge if bioenergy development continues its recent trajectory. Forest clearance will result where measures to protect and sustainably manage forests are ineffective or not upheld.

Loss of forest area will lead to carbon release and biodiversity losses. Ownership and use rights may also be affected where land is under traditional ownership or rights are not fully recognized. Soybean, sugar cane and oil-palm have all been associated with deforestation, which has contributed significantly to greenhouse gas emissions in countries where production of these crops has proliferated (GRAIN, 2007).

Recent studies have suggested that economic incentives to produce biofuels increasingly cause conversion of forest or grasslands, thereby releasing carbon dioxide stored in plants and soils through decomposition or fires (Searchinger *et al*., 2008). The significance of taking land-use change into carbon calculations for bioenergy development cannot be ignored. It has been estimated, for example, that if secondary forest is replaced with sustainably produced oil-palm, it will take 50–100 years to recapture lost carbon (Butler, 2007b)

Large areas of rainforest have been and are being cleared to make room for oil-palm plantations. The world's most significant areas of oil-palm plantation are in Indonesia and Malaysia. It has been estimated that approximately 17 to 27 percent of Indonesian deforestation may be explained by the establishment of oil-palm plantations, and in Malaysia the figure may be as high as 80 percent. In Indonesia, 3.6 million hectares of land are under oil-palm plantations and this figure is increasing by around 13 percent per year (FAO, 2007c). At the same time an average of 1.8 million hectares of forests are disappearing annually – equivalent to 2 percent of the national forest cover. This has not only caused large emissions of carbon dioxide into the atmosphere, but has increased the threat to several endangered species (UNECE/FAO, 2007).

Carbon dioxide emissions are particularly immense when oil-palm plantations are established on drained peat lands and, according to a study by Hooijer *et al.* (2006), 27 percent of oil-palm plantations are located in such areas. Carbon dioxide emissions from drained peat lands in Indonesia include 1 400 mega tons from peat land fires and 600 mega tons from decomposition of drained peat lands. This is estimated to equal almost 8 percent of global emissions from fossil fuel burning, and places Indonesia in third place in terms of global carbon dioxide emissions after the United States and China (Hooijer *et al*., 2006). There is evidence that bioenergy products, including some destined for export, contribute to this trend.

For example, significant amounts of palm oil are used for biodiesel production, primarily for use in Europe (Carrere, 2001; Colchester *et al*., 2006).

An increase in bioenergy use in industrialized countries could have widespread effects around the world. Currently, this is most likely for easily transportable liquid biofuels. With the advent of commercially viable liquid cellulosic biofuels, nations with abundant forest resources may be tempted to increase supply of bioenergy feedstocks, resulting in forest loss where sustainable management principles are not followed.

Large areas of degraded forest are also likely targets for the expansion of bioenergy plantations. Although not in pristine condition, such forests still maintain high levels of biodiversity and large amounts of carbon and may also provide important safety nets for local people in terms of food and materials production. Whether such areas can be sustainably managed for multiple goods and services including bioenergy production remains to be seen, but recent trends do not incite confidence.

In 2007, the Chinese State Forestry Administration (SFA) announced an initiative to develop two *Jatropha curcas* plantation bases in Yunnan and Sichuan Provinces for biofuel production. The SFA has since announced its intention to devote more than 13 million hectares of forestland to biofuels expansion, and the Yunnan Provincial Forestry Department plans to develop 1.3 million hectares of plantations by 2015 with the aim of producing four million tonnes of bioethanol and 600 000 tonnes of biodiesel annually (Liu, 2007). It is claimed that these plantings will be carried out on degraded forestlands and croplands, which have been estimated to amount to 4 million hectares in Yunnan Province alone. The southwestern areas of China have many forest areas with high biodiversity and land protection values (Perley, 2008).

Before implementation, countries need to assess greenhouse gas emissions and other environmental implications associated with various bioenergy alternatives in terms of a full life cycle – i.e. the full range of environmental impacts associated with production, including land-use change. The potential for bioenergy to reduce greenhouse gas emissions is well recognized. Relevant projects are well represented in the current global pipeline of actions to be funded under the Clean Development Mechanism (CDM) of the Kyoto Protocol. The CDM and other mechanisms should help overcome the financial barriers to carbon-efficient biofuel development, but because of complex rules and processes, access to the CDM itself by less developed countries is currently restricted (Peskett *et al.*, 2007).

6. Policy options and recommendations

Global energy consumption will continue to grow. Despite concerns about climate change and energy security, fossil fuels will continue to be the main source of energy. At the same time, high fossil fuel prices will encourage countries to become more energy efficient. The gradual conversion from fossil fuels to alternative fuels for the generation of power and for transport is already under way. Investments in bioenergy research and development are increasing. Technologies may soon be available to convert cellulose to liquid biofuels on a large-scale at economically attractive prices. This could have considerable impact on the future management of forests.

In most countries, policies and programmes to promote bioenergy development are still in their early stages. Most programmes focus on liquid fuels, especially for the transport sector. These policies and programmes tend to be limited in terms of scope, with more attention on regulatory measures than on investments in areas such as research and development, market liberalization, information and training. To date there has been relatively little transfer of technology or information about bioenergy from developed to developing countries.

Several developing countries have enormous potential to produce energy from forests and trees outside forests with relatively low investment and risk, but this potential is not properly reflected in national energy development strategies. Poor forest management and lack of proper data collection – often the result of widespread illegal forestry operations – frequently prevents assessment of the full economic and social potential of forestry and of wood energy production. Putting forestry on a sustainable and transparent footing will provide multiple benefits including improved energy production.[1]

Large bioenergy projects require extensive land area and can affect food security, social structures, biodiversity, the wood processing industry and the availability of wood products. To mitigate these impacts, land-use planning, consideration of policies in other sectors and effective governance are necessary. The involvement of all stakeholders when developing bioenergy strategies is also of great importance in balancing trade-offs between economic, social and environmental impacts and benefits.

[1] Recommendations in this section are largely drawn from the FAO High-Level Special Event on Forests and Energy, Rome, 17–24 November 2007; the International Tropical Timber Organization (ITTO) International Conference on Wood-based Bioenergy, Hanover, Germany, 17–19 May, 2007; the United Nations Economic Commission for Europe (UNECE) Workshop on Mobilizing Wood Resources, Geneva, 11–12 January 2007; and the UNECE/FAO Policy Forum on Opportunities and Impacts of Bioenergy Policies and Targets on the Forest and Other Sectors, Geneva, Switzerland, 10 October 2007.

In a national strategy, it is important to consider potential carbon and energy efficiencies of forest- and agriculture-based energy as well as cost-effectiveness and environmental performance. Planting trees can help mitigate climate change, combat erosion and restore ecosystems especially in degraded areas; but large-scale monoculture plantations can have negative impacts on soil and water resources.

Developing countries tend to have limited financial resources and human capacity, so bioenergy development should first explore opportunities based on already available biomass and proven technology. Integrating energy generation into forest industrial operations is a competitive way of reducing risks, increasing profitability and improving forest management. It also strengthens energy security and contributes to climate change mitigation and should thus be a priority area for exploration.

All countries would benefit from better information about wood energy feedstocks, including biomass recovered from forest operations and trade of forest biomass. Resources are needed to assess bioenergy and wood energy development potential, in particular:

- quantifying the potential of forest biomass for the generation of different energy outputs (e.g. heat, power, cellulosic liquid biofuel);
- evaluating the potential contributions of natural forests, woody biomass outside forests, energy plantations, residues and postconsumer material to wood energy production;
- determining trade-offs between different land-use decisions.

Traditional analysis of wood supply and demand, centred on wood removals from forests and wood input to industries is no longer fully adequate. Therefore, in more advanced countries an updated approach based on wood resource balances, is likely to be beneficial. To the extent possible, information collection should be aligned to current reporting processes, in particular the FAO Global Forest Resources Assessment (FRA).

All countries need to develop clear national-level policy goals for forests and energy that reflect the principles of sustainable development and sustainable forest management. Goals should account for national and international impacts as well as impacts between economic sectors. Consideration should also be give to trade-offs between wood energy, agrofuels and other energy sources and land-use options. The following points should be considered when developing wood energy policy at the national level.

- Policy processes should address bioenergy as a cross-sectoral issue and integrate energy into forest, agriculture and other land-use policies.
- Policy processes should involve adequate consultation and analysis of environmental, economic and social impacts in the context of specific regional, national and local conditions.
- Information flow to forest owners, tenure holders, the general public and consumers should be improved to support informed decisions about management of forest resources.
- Policy processes should consider rural employment, environment protection, land-use management, the forest products sector and other relevant areas to tap possible synergies and avoid negative impacts.

- Policy should provide broad support for facilitating bioenergy development including education and training, research and development and through transport and infrastructure measures, and not only incentives to producers, distributors and consumers.
- Policy processes should strive to create an appropriate balance between agriculture and forestry, as well as between imported and domestic biomass sources. Contingencies should also be taken to avoid competition with food production.
- The impacts of bioenergy policy on other economic sectors should be considered to avoid creating market distortions.
- Governments should verify that strategies and legislation outside the forestry sector do not have a negative effect on wood mobilization for bioenergy.
- Policies should be monitored regularly and systematically to avoid negative impacts on the environment and rural communities.
- Steps should be taken to avoid the destruction of valuable natural resources and biodiversity.

In relation to wood supply and the wood industry the following issues should be addressed:

- sustainable mobilization of wood resources in relation to legal and institutional constraints (e.g. forest ownership structures), access to data, forest infrastructure, and adequate prices for wood;
- supportive laws, regulations and policies, as well as information and motivation of forest owners, entrepreneurs and other actors;
- efficiency gains through more intensive use of existing forest resources, including wood assortments and forest-based and industry residues not currently used, woody biomass from outside the forest; postconsumer recovered wood products;
- the long-term expansion of the forest area and enhancements in the productivity of forest resources, such as silvicultural and genetic innovations.

Transfer of energy- and resource-efficient technologies for wood-based bioenergy to developing countries will be of considerable importance in achieving the climate change objectives of bioenergy development. The present situation represents a major opportunity for the forestry sector to find new roles and to contribute to the security of energy supply and to the mitigation of climate change by replacing fossil fuels and by sequestering carbon in forests and in forest products.

Glossary

There is as yet no consistent international usage of bioenergy terminology. In this paper the terms used have the following meanings.

Agro-energy
Energy derived from purposely-grown crops, and from agricultural and livestock by-products, residues and wastes.

Biodiesel
Biofuel produced from various feedstocks including vegetable oils (such as palm oil, oilseed, rapeseed, jatropha and soybean), animal fats or algae.

Bioenergy
All types of energy derived from biofuels including wood energy and agro-energy.

Bioethanol
Biofuel produced from sugar-rich plants (such as sugar cane, maize, beet, cassava, wheat, sorghum) or starch.

Biofuel
Any solid, liquid or gaseous fuel produced from biomass.

Biomass
Organic material both above and below ground and both living and dead, such as trees, crops, grasses, tree litter, and roots.

Biorefineries
A new generation of refineries expected to produce not only power and heat, but also transportation fuels and industrial products.

Black liquor
A liquid woodfuel, a by-product of the pulp industry.

Cellulose
Principal organic constituent in land plants, found in wood in association with hemicellulose and lignin.

Energy crop
A plant grown to produce biofuels, or directly exploited for its energy content.

Commercial energy crops are typically densely planted, high yielding crop species such as *Miscanthus*, *Salix* or *Populus.*

Feedstock
Any biomass destined for conversion to energy or biofuel. For example, corn is a feedstock for ethanol production and soybean oil is a feedstock for biodiesel. Cellulosic biomass has the potential to become a significant feedstock source for biofuels.

First-generation biofuel
Fuel produced from purposely grown crops.

Forest biomass
Any biomass found in forests including trees, leaves, branches, roots. Specific types of biomass targeted for use in energy systems include: tops and branches of trees left after timber harvests, poor quality trees in managed forests, trees removed during land clearing operations, wood waste from urban areas, and wood residues produced by sawmills.

Forest cover
Percentage of land within a specific area covered by forests.

Fossil fuel
A non-renewable energy source produced by the remains of living organisms that built up underground over geological periods in liquid (oil), solid (coal, peat) and gaseous (natural gas) forms.

Fuel crop
See Energy crop.

Fuelwood
Wood in the rough (such as chips, sawdust and pellets) used for energy generation.

Gaseous woodfuel
Gas produced from the gasification of solid and liquid woodfuels.

Greenhouse gas
Chemical compounds in the atmosphere that trap sun radiation and heat.

Jatropha
Mainly *Jatropha curcas*, an evergreen shrub found in Asia, Africa and the West Indies. Its non-edible seeds contain a high proportion of oil which can be used to produce biodiesel.

Liquid biofuel
Fuel of biological origin that is used in liquid form, such as biodiesel and bioethanol, currently manufactured predominantly from food crops including oil-palm, sugar cane, maize, rapeseed, soybeans, and wheat.

Liquid woodfuel
Black liquor and ethanol, methanol and pyrolytic oil.

Municipal by-products
Waste products such as sewage sludge and landfill gas, as well as municipal solid wastes.

Non-renewable fuel
Fuel from a finite resource that will eventually dwindle and become too expensive or too environmentally damaging to retrieve. Includes fossil fuel from coal, petroleum and natural gas and nuclear energy.

Pulpwood
Wood assortments used in making paper.

Pyrolysis
The chemical decomposition of organic materials by heating in the absence of oxygen; a method of converting biomass into biodiesel.

Renewable energy
Energy produced from sources that can be renewed indefinitely, for example, hydro-, solar, geothermal, and wind power, as well as sustainably produced biomass.

Roundwood
Wood in its natural state as felled, with or without bark.

Sawnwood
Wood in sawn form.

Second-generation biofuel
Fuels produced from cellulosic materials, crop residues and agricultural and municipal wastes.

Solid biomass
Wood, wood waste and other solid waste.

Syngas
Short for synthetic gas. A mixture of carbon monoxide and hydrogen resulting from high temperature gasification of organic material such as biomass. After clean-up can be used to synthesise organic molecules such as synthetic natural gas or liquid biofuels.

Traditional biomass
Woodfuels, agricultural by-products and dung burned for cooking and heating purposes. In developing countries, still widely harvested and used in an unsustainable and unsafe way. Mostly traded informally and non-commercially.

Wood energy
Energy derived from fuelwood, charcoal, forestry residues, black liquor and any other energy derived from trees.

Wood energy feedstocks
Wood and biomass recovered from forests and trees for use in creating fuel.

Woodfuel
Fuel from wood sources including solids (fuelwood and charcoal), liquids (black liquor, methanol, and pyrolitic oil) and gases from the gasification of these fuels.

Wood pellets
Small particles used for energy generation made of dried, ground and pressed wood.

Wood residues
Wood left behind in the forest after forest harvesting, and wood by-products from wood processing, such as wood chips, slabs, edgings, sawdust and shavings.

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154

FAO FORESTRY PAPER

Forests and energy

Key issues

Soaring energy consumption and fossil fuel prices, increasing greenhouse gas emissions and concerns over energy import dependence are driving the search for alternatives to fossil fuels for energy production. Biofuels currently constitute the largest source of renewable energy produced on earth. As biomass, wood offers some of the highest levels of energy and carbon efficiency. This publication explores the relationship between forests and energy. It considers the present and future contribution of wood in the production of bioenergy as well as the effects of liquid biofuel crop development on forests. The paper begins with an overview of global energy supply and demand with projections to the year 2030. The contribution of wood energy is then considered in the context of a general discussion of a variety of bioenergy crops and their use in the production of first- and second-generation biofuels. The analysis evaluates the payoffs in developing different sources of bioenergy and the risks of land conversion. It also discusses market forces and ongoing technological innovations for wood energy production. Policy options and recommendations for bioenergy development are given, stressing the importance of integrated planning and monitoring of land use, and the transfer of advanced wood energy technologies to developing countries. This publication will be useful to both specialized and general audiences interested in learning more about the role of forests in energy production.

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