1. Introduction and overview

Wood is society's oldest source of energy. Its use for cooking and heating remains vital to the daily energy needs of over two billion people in developing countries. It is also a "new" energy source in the sense that modern and efficient applications for wood energy are increasingly being used, especially in member countries of the Organisation for Economic Co-operation and Development (OECD), to produce cost-effective, high-quality energy services at various scales. The complexity of woodfuel issues arises in part from this dual role: woodfuel is both an intimate part of basic energy needs in developing countries and integral to the ambitious plans for renewable energy in many OECD countries (and increasingly in some developing countries).

The notion of woodfuels as a contributor to climate change mitigation is more recent and remains controversial. Any analysis of the energy and environmental implications of woodfuels spans a wide spectrum of issues, including forest management, agricultural practices and sociocultural traditions as well as the basic economics of formal and informal energy markets. Such an analysis is further complicated by the many non-energy uses of woody biomass – such as in housing, furniture, paper, chemicals and many other goods and services.

DEFINITIONS

Woodfuels are fuels derived from forest-based or woody biomass. They comprise the largest category of biofuels by consumption, due largely to the widespread use of wood and charcoal for cooking in developing countries. Other sources of biofuels include vegetable oils, herbaceous energy crops, animal and plant residues and various by-products (Table 1).

According to the Unified Bioenergy Terminology (FAO, 2004), woodfuels are defined as "all types of biofuels derived directly or indirectly from woody biomass". They include biomass derived from silvicultural activities (such as thinning and pruning) and harvesting and logging (such as tops, roots and branches), as well as industrial by-products derived from primary and secondary forest industries that are used as fuel. They can be divided into four groups according to their production or supply:

- ***Direct woodfuels*** are woody materials that are directly removed from forests, other woodlands (including shrubs), or other lands able to supply energy demands, including both inventoried (i.e. recorded in official statistics) and non-inventoried woodfuels.
- ***Indirect woodfuels*** include industrial by-products derived from primary wood industries (e.g. sawmills, particleboard plants and pulp and paper mills) and secondary industries (e.g. joinery and carpentry) that produce residues such as sawmill scrap, sawdust, shavings and black liquor.

- ***Recovered woodfuels*** come from socio-economic activities outside the forest and wood-processing sectors, such as waste from construction sites, the demolition of buildings and containers; they may be combusted or transformed into chips, pellets, briquettes or powder.
- ***Wood-derived fuels*** are those fuels produced from woody sources using various conversion processes. They include liquid and/or gaseous fuels made from woody sources through ligno-cellulosic conversion, Fischer-Tropsch synthesis and pyrolysis.

Table 2 gives examples of solid, liquid and gaseous woodfuels according to the Unified Bioenergy Terminology classification. The distinction between "recovered" and "wood-derived" depends to some extent on what is considered to be a primary product. It is convenient to view pyrolysis gases and oils, for example, as being "recovered" alongside the production of char. Wood-derived fuels are normally those that have undergone conversion processes and thus in some sense involve the dedicated production of biofuel. The term "fuelwood" is used to describe direct woodfuels where the original composition of the wood is preserved.

TABLE 1
Unified Bioenergy Terminology biofuels classification

Category	Woodfuels	Agrofuels		Others (including mixtures)
		herbaceous biomass	biomass from fruits and seeds	
Energy crop – direct	Energy forest trees Energy plantation trees	Energy grass Energy whole cereal crops	Energy grain	
By-products[a] – direct	Thinning by-products Logging by-products	Straw	Stones, shells, husks	Animal by-products Horticultural by-products Landscape management by-products
By-products – indirect	Wood processing industry by-products Black liquor	Fibre crop processing by-products	Food processing industry by-products	Biosludge Slaughterhouse by-products
End-use materials – recovered	Used wood	Used fibre products	Used products of fruits and seeds	Kitchen waste Sewage sludge

Source: FAO, 2004.
[a] The term "by-products" includes solid, liquid and gaseous residues and wastes derived from biomass processing activities.

TABLE 2
Examples of solid, liquid and gaseous woodfuels, by classification type

Category	Solid	Liquid	Gaseous
Direct	Fuelwood, charcoal		Synthesis gas
Indirect	Sawdust	Black liquor	
Recovered	Construction waste	Pyrolysis oil	Pyrolysis gas
Wood-derived		Lignocellulosic ethanol, Fischer-Tropsch fuels	

Source: Adapted from FAO, 2004.

TABLE 3
Estimated amounts and shares of global primary biomass consumed for energy

Type of biomass	Energy *(EJ)*	Share *(%)*
Agricultural sources		
Agro-energy crops	1.5	3
Residues[a]	3.5	7
Woody sources		
Fuelwood	33.5	67
Charcoal	3.5	7
Recovered products and residues	6.1	12
Black liquor	0.5	1
Municipal solid waste	1.5	3

Source: Estimated from IPCC, 2007; IEA, 2009a.
[a] Agricultural residues include liquid fuels made from by-products (e.g. ethanol from molasses).

DISTRIBUTION OF BIOMASS USE

Biomass energy accounts for about 10 percent (47 exajoules [EJ]) of the roughly 500 EJ of primary energy[1] consumed globally, which is more than is produced from all other renewables and nuclear power combined (IEA, 2009a). According to Heinimö *et al.* (2007), over two-thirds (32 EJ) of this biomass energy is used for cooking and heating in developing countries and the remaining 15 EJ is consumed in industrialized countries both for industrial applications within the heat, power and road transportation sectors and for the heating purposes of the private sector.

All woody sources combined account for 87 percent of all biomass used globally for energy; fuelwood accounts for two-thirds (Table 3). Fuelwood and charcoal together account for 74 percent, nearly all of which is produced and consumed in developing countries. Despite the increased consumption of and attention on liquid biofuels in recent years, they represent only an estimated 3 percent of biomass-based fuels used globally for energy.

The commercial biomass supply for heat and electricity consists mainly of prepared biomass and waste, also from woody sources. Wood pellets, woodchips and other types of woody biomass are used widely for small-scale heat and power production and in household applications for heating and hot-water supply. Wood wastes are also used and traded internationally, especially in northern Europe, where landfill regulations encourage their use for heat and power production (IEA, 2008).

The share of biomass in total national energy consumption of a country or region is generally correlated with the level of economic development and industrialization. Biomass energy constitutes almost half of total primary energy in Africa and a

[1] Primary energy is energy found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels as well as other forms of energy received as input to a system.

TABLE 4
Biomass and total primary energy supply, selected regions, 2006

Region	Total primary energy (EJ)	Biomass energy (EJ)	Share of biomass in total supply (%)	Share of residential use in total biomass supply (%)
Latin America	22.1	4.2	19	28
Africa	25.6	12.1	47	71
Asia	55.4	14.0	25	78
China	79.0	9.4	12	99
Near East	21.8	0	0	69
OECD total	230.7	8.8	4	26

Source: IEA, 2010a.

significant share in Asia and Latin America; in some of the least developed countries in Africa and Asia the share is more than 80 percent. In most developing countries, biomass use is still growing but its share in total energy consumption is declining because of faster growth in the consumption of fossil fuels. Most of the consumption of biomass energy in developing countries and regions is in the residential sector for cooking and heating. An exception is Brazil, where a significant share of biomass energy is consumed by industry, particularly charcoal in the steel industry; this skews the proportion of biomass energy used in the residential sector in Latin America (Table 4).[2]

Biomass use for energy in developed countries fell to very low levels after the Second World War because of the widespread availability of cheap and convenient fossil fuels. In recent years, however, growing concerns about climate change and the insecurity of global energy supplies have led to the increased use of biomass energy.

TRADITIONAL BIOMASS USE

Biomass in the form of fuelwood, agricultural residues and animal dung has been used by society for millennia as a source of energy for cooking and heating. Biomass also fuelled the initial stages of the industrial revolution and was the biggest source of energy in industrializing countries until overtaken by coal in the late 1800s. The majority of households in the developing world continue to rely on biomass for cooking; the share is highest in sub-Saharan Africa, at 76 percent (Table 5).

Many households use several biofuels. The reasons for doing so vary considerably, including cultural preferences and availability as well as economic factors (Sanchez, 2010). In general, fuelwood is estimated to account for 80 to 100 percent of biomass use, although the percentage is lower in East and South Asia, where the use of agricultural residues and/or dung is significant (Table 6).

Apart from the household sector, biomass is also used by small and medium-sized enterprises in developing countries in a variety of traditional commercial

---

2 Throughout this book, totals in tables may be inconsistent due to rounding.

TABLE 5
Estimated number of people depending on biomass for cooking in selected countries/regions

Region/country	No. of people *(million)*	Share of total population *(%)*
Sub-Saharan Africa	575	76
North Africa	4	3
India	740	69
China	480	37
Indonesia	156	72
Rest of Asia	489	65
Brazil	23	13
Rest of Latin America	60	23
World	**2 528**	**52**

Source: IEA, 2009a.

TABLE 6
Estimated biomass/bioenergy consumption, by region (million m^3)

Region	Fuelwood	Crop residues	Dung	Charcoal
North America	41	0	0	0
Latin America	80	0	0	16
Africa	371	52	0	14
Europe	147	0	0	0
South Asia	344	76	75	3
East Asia	193	323	0	0
Southeast Asia	164	43	0	6
Oceania	10	0	0	0
World	**1 351**	**495**	**75**	**39**

Source: Fernandes *et al*., 2007.

applications. Large quantities of fuelwood are consumed in the production of charcoal, which is used as a household fuel and also has many commercial and industrial applications.

THE ROLE OF MODERN BIOENERGY

"Modern" bioenergy is normally distinguished from traditional biomass use on the basis of higher efficiency in conversion and a higher quality of delivered energy services. The traditional use of solid biomass as fuel delivers only difficult-to-control heat; modern bioenergy technology is more versatile and controllable. Modern bioenergy production is more likely to be sustainable in the long term compared to traditional uses due to savings in land, water and other resources as a result of higher efficiency in biomass production and greater precision in meeting demand for energy services for different end-users and particular applications (Leach and Johnson, 1999).

Like other renewable energy sources, bioenergy can make valuable contributions to climate change mitigation and the transition towards sustainable energy. Moreover, bioenergy has certain advantages over other renewables. For example:

- Biomass is stored energy. It can be drawn on at any time, unlike daily or seasonally intermittent solar, wind, wave and small hydro sources, whose contributions are all constrained by the high costs of energy storage (Worldwatch Institute, 2007).
- Biomass can be transformed into all forms of energy carriers – electricity, gas, liquid fuel and heat. Solar, wind, geothermal, wave and hydro are limited to electricity and, in some cases, heat. Biomass energy systems can produce energy in several different carriers at the same facility or implementation platform, thereby enhancing economic feasibility and reducing environmental impact (Leach and Johnson, 1999).

Modern bioenergy also has valuable rural and/or economic development dimensions that have contributed to its growing market share in recent years, including the following.

- ***The provision of rural jobs and income to people who grow or harvest bioenergy resources*:** Bioenergy tends to be more labour-intensive than other energy resources, depending on local labour costs and the extent to which mechanisation is appropriate and cost-effective.
- ***Improving the profitability of the agricultural, food-processing and forest sectors*:** Biomass residues and wastes that may have substantial disposal costs can instead be converted to energy for sale or for internal use to reduce energy bills.
- ***Helping to restore degraded lands*:** Growing trees, shrubs or grasses on degraded land can reverse damage to soils and provide a valuable bioenergy resource.

Modern bioenergy also presents challenges and risks for both developed and developing countries. For example, the demand for bioenergy in developed countries and land-constrained countries such as China and India has raised the prospect of growing large-scale agro-energy crops in developing countries for export. This could lead to deforestation and increased competition for land in developing countries and exacerbate existing land-use conflicts.

Nevertheless, deforestation and other land-use changes have a wide range of causes, most of which existed well before modern bioenergy production emerged as a major land-use option. Land-use change is driven more generally by population growth and accompanying economic growth and development, which lead to increased demands for land to produce food, feed, fibre and fuel. If it is to be sustainable, a major expansion of global bioenergy supply will thus require significant improvements in agricultural yields and efficiency and in forest management (Schubert *et al.*, 2009). Such improvements are likely to have positive spin-offs for ecosystem services and non-energy products in the agricultural and forest sectors.

OBJECTIVES AND STRUCTURE OF THIS REPORT

The objective of this report is to review and synthesize the following key elements of the debate on the role of woodfuels in climate change mitigation:

- the status of forest resources and their potential to support expanded bioenergy production;
- the national, regional and global roles of woodfuels within the overall energy resource base;
- the dynamics of future energy demand and their implications for the expanded use of woodfuels;
- cost-effective applications of woodfuels for fossil-fuel substitution;
- techno-economic characteristics of selected greenhouse gas emission reduction options;
- socio-economic drivers in the implementation of woodfuel projects and programmes;
- environmental impacts that facilitate or constrain the expanded use of woodfuels;
- financing options for woodfuel projects and programmes;
- key research and development issues related to woodfuels.

Together, these elements will determine the short-term scope for woodfuels to support climate change mitigation regionally and globally; each is the subject of a chapter in this report. Where appropriate and where the data allow it, a distinction is made between Annex I countries, which have greenhouse gas reduction obligations under the Kyoto Protocol, and non-Annex I countries, which have no such obligations.

WOODFUELS INCLUDED IN THIS REPORT

The scope of this report is limited to solid woodfuels and their applications. Solid woodfuels are fuelwood, charcoal, prepared biomass (e.g. woodchips and pellets) and the various residues and recovered products from forest and wood-processing industries. Except in Chapter 10, which examines woodfuel gasification technology, liquid and gaseous biofuels are not considered, for the following reasons:

- The commercial use of lignocellulosic ethanol and/or other liquid or gaseous fuels derived from woody biomass is currently insignificant; even if such fuels could be deployed on a large scale in the short term, it would mainly be in OECD countries, where the appropriate technical infrastructure exists.
- An analysis of liquid biofuels and transport-sector substitution options is outside the scope of this study: biofuel initiatives in the transport sector often arise from energy security goals and are less likely to have climate change mitigation as a primary motivation.
- Non-solid industrial wood by-products such as black liquor have specialized applications in their respective industries (e.g. pulp and paper): their use in climate change mitigation could be cost-effective but is unlikely on a large scale.
- Developing countries rely heavily on woody biomass, mainly in the form of fuelwood and charcoal, and therefore this sector has special relevance in the short-to-medium term.

Nevertheless, several parts of this report are applicable to all woodfuels, including the socio-economic and environmental impacts, financing options and the overall development implications of the more intensive and efficient use of woodfuels. Some

TABLE 7
Summary of units used in woodfuel measurement, and typical density and energy values

Type	Primary data units	Density *(tonnes/m³)*	Net calorific value *(MJ/kg)*	Moisture *(%, dry basis)*
Direct woodfuels	Volume	0.725	13.8	30
Charcoal	Mass, volume		30.8	5
Indirect	Mass, volume	0.725	13.8	
Recovered	Mass, volume	0.725		

Source: FAO, 2004.

of these are also relevant for agricultural sources of biomass; however, the issues associated with the large-scale use of agro-energy crops to produce liquid biofuels for transport is generally not addressed in this report.

ACCOUNTING UNITS AND CONVERSION

Solid woodfuels are generally measured by volume (cubic metres [m^3]) or mass (tonnes). However, both mass density (tonnes per m^3) and energy density (megajoules [MJ] per m^3 or MJ per kilogram [kg]) vary depending on factors such as tree species, moisture content and the extent of pre-processing. A certain amount of volatile substances and/or non-combustible material is contained in the ash that remains after combustion. The *net calorific value* is determined in reference to a specified moisture content, declining from approximately 18.5 MJ per kg at zero moisture to zero at full moisture (88 percent); the energy content of air-dried wood at 12 to 20 percent moisture has been estimated to have, on average, an energy content of 13 to 16 MJ per kg (FAO, 2004). Table 7 summarizes reporting measures and typical mass and energy densities.

In this report, solid woodfuels are referred to in any of three units (volume, mass or energy) depending on how the data were originally reported and the appropriate unit for a particular application, market or end-use. Fuelwood is normally obtained or sold in cubic metres, whereas charcoal is sold by the tonne. Indirect and recovered woodfuels may be measured as either volume or mass, depending on the context and source. The energy content of charcoal has less variation than fuelwood; nevertheless, the species and method used have an effect due to factors such as the completeness of combustion and remaining moisture.