ISSN 0258-6150

FAO
FORESTRY
PAPER

162

What woodfuels can do to mitigate climate change

Cover photo:
© FAO/22104/J.Koelen

What woodfuels can do to mitigate climate change

FAO
FORESTRY
PAPER

162

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2010

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

ISBN 978-92-5-106653-9

All rights reserved. FAO encourages reproduction and dissemination of material in this information product. Non-commercial uses will be authorized free of charge, upon request. Reproduction for resale or other commercial purposes, including educational purposes, may incur fees. Applications for permission to reproduce or disseminate FAO copyright materials, and all queries concerning rights and licences, should be addressed by e-mail to copyright@fao.org or to the Chief, Publishing Policy and Support Branch, Office of Knowledge Exchange, Research and Extension, FAO, Viale delle Terme di Caracalla, 00153 Rome, Italy.

© FAO 2010

Contents

Figures

Tables

Foreword

Climate change involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes. It cannot be addressed or comprehended in isolation of broader societal goals such as equity or sustainable development, or other existing or probable future sources of stress. Both adaptation and mitigation are fundamental in the climate change debate. The International Panel on Climate Change (IPCC, 2007) defines mitigation as: "Technological change and substitution that reduce resource inputs and emissions per unit of output". The Stern Review identifies several ways of mitigating climate change. These include reducing demand for emissions-intensive goods and services, increasing efficiency gains, increasing use and development of low-carbon technologies and reducing non-fossil fuel emissions (Stern, 2007).

At the core of most proposals is the reduction of greenhouse gas emissions through reducing energy use and switching to cleaner energy sources. There are opportunities to switch to less carbon-intensive fuels on both the demand and the supply sides. Demand-side fuel-switching strategies to reduce carbon emissions include the use of bioenergy to supply residential, industrial and transport energy demands. Many developing countries have already successfully pursued such options, reducing the growth of their energy demand and consequent carbon emissions.

The publication explores the scope and potential for woodfuels to replace fossil fuels thereby contributing to climate change mitigation. The potential for and implications of woodfuel development for climate change mitigation and the current woodfuel offset mechanisms in place and their relative emissions reduction potentials were analysed.

Many barriers have been identified that preclude the full use of this mitigation potential. Policy reforms to encourage environmental sustainability, increased productivity, improved infrastructure and planning are essential for large-scale implementation.

José Antonio Prado
Director, Forest Management Division
FAO Forestry Department

Acknowledgements

This publication has benefited from the expertise of a number of experts. The study was initiated by Simmone Rose and commenced with the preparation of country case studies which have been published as the Forests and Climate Change Working Paper 6. The present publication was prepared by the Stockholm Environment Institute (SEI Sweden). Francis X. Johnson, Patricia V. Tella, Alesia Israilava, Takeshi Takama, Rocio Diaz-Chavez and Frank Rosillo-Calle contributed to the publication on behalf of SEI.

The publication incorporates comments from Neil Bird, Susan Braatz, Jana Hanova, Warren Mabee and Jack Sadler and was revised and prepared for publication by Simmone Rose and Andrea Perlis.

Acronyms and units of measurement

AIJ	activities implemented jointly
ALRI	acute lower respiratory infection
ACM	approved consolidated methodology
AM	approved methodology
AMS	approved methodology for small-scale projects
ARI	acute respiratory infection
CBWP	community-based woodfuel production
CDM	Clean Development Mechanism
CEN	European Committee for Standardization
CER	certified emission reduction
CO_2	carbon dioxide
EJ	exajoule
EU	European Union
g	gram
GEF	Global Environment Facility
Gg	gigagram
GJ	gigajoule
GtC	gigatonne of carbon
$GtCO_2eq$	gigatonne carbon dioxide equivalent
ha	hectare
HS	Harmonized Commodity Description and Coding System
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JI	joint implementation
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
LPG	liquefied petroleum gas
Mbdt	million bone dry tonnes
MJ	megajoule
Mt	megatonne
MtC	megatonne of carbon
MtDM	megatonnes of dry matter
m^3	cubic metre
OECD	Organisation for Economic Co-operation and Development
PIC	product of incomplete combustion
PJ	petajoule

REDD	reduced emissions from deforestation and forest degradation
SEI	Stockholm Environment Institute
tCO_2eq	tonnes of CO_2 equivalent
TJ	terajoule
VCU	voluntary carbon unit
VCS	Voluntary Carbon Standard

Summary

Woodfuels currently account for a greater share of global energy consumption than all other forms of "renewable" energy combined. The overwhelming majority of this consumption, however, is based on the traditional use of wood and charcoal in developing countries. Due to the low efficiency of such use and the often poor quality of associated resource management, much woodfuel consumption is unsustainable.

A great deal of effort has been directed at improving access to alternative forms of energy and encouraging households to switch to them; nevertheless, traditional biomass will continue to constitute a major source of energy for the foreseeable future, especially in sub-Saharan Africa. Consequently, strategies are needed to enable the traditional biomass sector to both improve efficiency and manage woodfuel resources more sustainably.

At the same time, there is a growing market for modern and efficient bioenergy that uses wood in the form of pellets, residues and various types of dedicated feedstock supplies. Natural forests and planted forests both have distinct advantages in the provision of biomass feedstock supply. For medium-scale applications, combined heat and power systems have become cost-effective almost anywhere where there is sufficient heat demand that can be coupled to electricity demand. In large-scale applications, one of the simplest and most cost-effective options is the co-firing of biomass in coal-fired power plants.

Many other options can be usefully deployed, not only to mitigate climate change but also to address energy security concerns and to improve the quality of energy services. They include wood and charcoal use in industry, improved cook stoves, more efficient charcoal production and improved forest management that can result in the greater use of residues.

The technological and economic potential for the substitution of fossil fuels by woodfuels in heat and power generation is significant, and there is some additional substitution potential in the household, commercial and industrial sectors.

Worldwide, the use of biomass for heat and power could save more than 1 gigatonne of carbon (GtC) annually by 2030. The co-firing of biomass with coal could save nearly 0.5 GtC per year at fairly modest costs. Savings in the traditional biomass and charcoal sectors could amount to another 0.5 GtC, although considerable effort would be required in this sector to overcome the higher investment cost, the complex socio-economic and cultural issues around traditional biomass use and the transaction costs associated with providing the equipment and reliable biomass supply.

FAO/G. NAPOLITANO

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.

2. Forest resources and woody biomass

The availability of forest resources to meet the future demand for fuel and fibre will require the implementation of sustainable forest management, the better use of residues and waste, and the balancing of supply and demand across the various types of forests and other wood-based biomass resources. The high rates of deforestation that occurred in the second half of the twentieth century have raised concerns about the future use of forests for bioenergy. Much of that deforestation, however, was related to agro-industrial expansion. Local and community use of forest resources can often be more ecologically sound, since those who live in or near forests are more likely to recognize the need to preserve them for future use (Leach and Mearns, 1988). This chapter defines several types of forest and presents data on their extent, the availability of woody biomass and past and current use.

FORESTED AREA

Table 8 shows the area of forest, by region, over time. Roughly half the world's forests are in South and Central America and Europe (with the Russian Federation counted as part of Europe). In the period 1993–2007 the greatest rates of forest loss were in Africa and South America, while Asia, Europe and North America gained forest. The gain in Asia was due primarily to an expansion in the area of planted forests.

FAO (2006a) defines forest as land spanning more than 0.5 hectares with trees higher than five metres and a canopy cover of more than 10 percent, or trees able

TABLE 8
Global forested area, by region

Region	Forest area *(million ha)*				Share of global total *(%)*	Average annual rate of change, 1993–2007 *(%)*
	1993	1998	2003	2007		
Africa	686	664	643	627	16	-0.64
Asia	572	568	570	574	15	0.02
Europe	992	996	1 000	1 003	25	0.08
North America	610	612	613	614	16	0.04
South and Central America	979	957	934	915	23	-0.49
Oceania	211	209	207	206	5	-0.19
World	**4 051**	**4 006**	**3 967**	**3 937**		**-0.20**

Source: FAO, 2010a.

to reach these thresholds in situ. This definition does not include land that is predominantly under agricultural or urban land use, such as tree stands in fruit plantations, agroforestry systems and urban parks and gardens.

Natural forest is forest comprising native forest tree species only, with the possible exception of small areas of natural regeneration of introduced or naturalized species.

Forest plantations comprise forests of native or introduced species that have been established through planting or seeding, mainly for the production of wood or non-wood products or the provision of environmental services. It includes all stands of introduced species established for soil and water protection, pest control and the conservation of biological diversity, and areas of native species characterized by few species, straight lines of trees and even-aged stands.

Planted forests are those forests predominantly composed of trees established through planting and/or deliberate seeding of native or introduced species. This definition specifically recognizes the planted component of semi-natural forests comprising primarily native species, and forest plantations of primarily introduced species; thus, forest plantations are a subset of planted forests (Table 9).

Primary forests account for 36 percent of forest area but have decreased by more than 40 million hectares since 2000 (FAO 2010c). The decrease of primary forest area, 0.4 percent over a ten-year period, is largely due to reclassification of primary forest to "other naturally regenerated forest" because of selective logging and other human interventions.

Planted forests account for 7 percent of total forest area or 264 million hectares. During 2005–2010, the area of planted forest increased by about 5 million hectares per year. Most of this was established through afforestation, i.e. planting of areas not forested in recent times, particularly in China.

TABLE 9
Forest categories showing the planted forest subgroup

Primary	Modified Natural	Semi-natural		Plantation		Trees outside forests
		Assisted natural regeneration	Planted component	Productive	Protective	
			Planted forest subgroup			
Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed	Forest of naturally regenerated native species where there are clearly visible indications of human activities	Silvicultural practices for intensive management (weeding, fertilizing, thinning, selective logging)	Forest of native species, established through planting, seeding, coppice	Forest of introduced species and in some cases native species, established through planting or seeding mainly for production of wood or non-wood products	Forest of native or introduced species, established through planting or seeding mainly for provision of services	Stands smaller than 0.5 ha; trees in agricultural land (agroforestry systems, home gardens, orchards); trees in urban environments and scattered along roads and in landscapes

Source: Modified from FAO, 2006b.

WOOD PRODUCTS

The primary wood-based uses of forest resources are the production of fuelwood, used directly in households and businesses, and industrial roundwood, which is processed to varying degrees to produce a range of wood and wood-fibre products. In 2008, nearly two-thirds (63 percent) of the production of industrial roundwood was in North America and Europe (including the Russian Federation) (Table 10). The biggest change between 1988 and 2008 was the emergence of South America (mainly Brazil) as a major global producer and exporter of industrial roundwood.

The production and use of woodfuel is concentrated in Africa and Asia, where the traditional use of biomass for heating and cooking still predominates; together, Africa and Asia account for 75 percent of global woodfuel production and consumption (Table 11). Nevertheless, there has been a considerable divergence between these two regions: consumption is decreasing in Asia due to urbanization and the switch to modern energy sources and increasing in much of Africa due to population increases.

TABLE 10
Industrial roundwood production, by region

Region	1988		2008		Average annual rate of change 1988–2008 (%)
	(million m³)	*(%)*	*(million m³)*	*(%)*	
Africa	53	3	70	5	1.41
Asia	267	16	243	16	-0.46
Europe	605	36	505	32	-0.90
North America	598	36	489	31	-1.00
South and Central America	116	7	197	13	2.70
Oceania	30	2	52	3	2.81
World	**1 668**	**100**	**1 557**	**100**	**-0.35**

Source: FAO, 2010a.

TABLE 11
Woodfuel production, by region

Region	1988		2008		Average annual rate of change 1988–2008 (%)
	(million m³)	*(%)*	*(million m³)*	*(%)*	
Africa	424	25	638	34	2.06
Asia	777	46	754	40	-0.16
Europe	134	8	152	8	0.65
North America	100	6	47	2	-3.74
South and Central America	230	14	286	15	1.08
Oceania	9	1	16	1	2.94
World	**1 674**	**100**	**1 892**	**100**	**0.61**

Source: FAO, 2010a.

In the last two decades a significant market has emerged for processed forms of solid bioenergy, especially wood pellets. The technology for the pelletization of wood matured in the 1980s and 1990s and wood pellets are now produced and traded internationally on a significant scale, with major markets in Europe and North America. The magnitude of wood pellet production and trade is difficult to estimate because the Harmonized Commodity Description and Coding System (often referred to as the Harmonized System or HS) does not (yet) have a dedicated code for wood pellets. In 2008 the estimated global production was 11.5 megatonnes (Mt) and the estimated amount traded was 4 Mt (IEA, 2010b). With an average energy density of 17.5 gigajoules (GJ) per tonne, this amounts to 200 terajoules (TJ) produced and 70 TJ traded.

PLANTED FORESTS

Planted forests are playing an increasingly important role as a source of wood products and bioenergy. They are concentrated in Asia and Northern, Central and Eastern Europe: combined, these regions account for more than 75 percent of the world total area of planted forests (Table 12). The data presented in Table 12 were obtained from a detailed survey of 61 countries on various species, summarized here as softwoods (e.g. *Pinus* spp.) and hardwoods (e.g. *Acacia* spp. and *Eucalyptus* spp.). An estimated 1.4 billion m^3 of wood products were harvested from these planted forests in 2005, about 47 percent of which was devoted to industrial roundwood, 39 percent to pulp and paper and 10 percent to bioenergy (Carle and Holmgren, 2008).

The proportion of planted forests dedicated to bioenergy is likely to increase because second-generation (lignocellulosic) biofuels are likely to be sourced from planted forests (FAO, 2009). Moreover, those same planted forests could also serve feedstock markets for solid woodfuel applications, increasing their economic flexibility. The additional demand could, however, constrain efforts to achieve sustainable forest management. Thus, planted forests have strategic significance in terms of both energy security and environmental sustainability. Recognizing the

TABLE 12
Planted forest area, hardwoods and softwoods (million ha)

Region	Softwoods	Hardwoods	Total
Africa	1.7	7.8	9.5
Asia	34.2	90.6	124.8
Northern, Central and Eastern Europe	62.4	12.1	74.5
Southern Europe	4.6	4.7	9.3
North and Central America	26.1	1.7	27.8
South America	5.4	5.6	11.0
Oceania	2.9	0.7	3.6
World	**137.3**	**123.2**	**260.7**

Source: Carle and Holmgren, 2008.

growing importance of planted forests, FAO led a coordinated multi-stakeholder process to develop a set of guidelines for the management of planted forests (FAO, 2008). These provide decision-makers, investors and foresters with a tool for planning, managing and monitoring institutional, political, economic, social, cultural and environmental priorities.

WOODFUEL USE

Woodfuel consumption increased globally by 10 percent in the period 1989–2008, even though it decreased in both North America and Asia (Table 13). Recent increases in woodfuel use in Europe (in both total consumption and per capita consumption) are due to a combination of the increasing cost-effectiveness of biomass for combined heat and power production and incentives provided through the Directives on Renewable Energy of the European Union (EU) and related EU-wide strategies for increasing the use of renewable energy (European Commission, 2006, 2009).

Unprocessed fuelwood of various types constitutes by far the largest consumption category of woodfuels; together with charcoal, it forms the energy base of the world's poor. To a significant extent, the future use of wood energy to achieve climate and development goals thus depends on the pace of transformation in household and industrial uses of fuelwood and charcoal. Table 14 shows that per capita woodfuel consumption is declining in all listed regions except Europe.

CHARCOAL USE

In developing countries charcoal is generally produced at small-scale facilities in rural areas, traditionally in earth-pits or above-ground mounds. An earth-pit kiln involves placing wood in a pit dug into the ground and lighting it from the bottom; the pit is then covered with green leaves or metal sheets and earth to prevent

TABLE 13

Average annual consumption of woodfuel, by region[a]

Region	1989–1993		1994–1998		1999–2003		2004–2008	
	Volume *(million m³)*	Share of world total *(%)*	Volume *(million m³)*	Share of world total *(%)*	Volume *(million m³)*	Share of world total *(%)*	Volume *(million m³)*	Share of world total *(%)*
Africa	452	27	505	29	528	30	596	32
North America	96	6	86	5	48	3	47	3
South America	164	10	175	10	186	10	194	10
Asia	787	46	798	46	822	46	784	42
Europe	121	7	85	5	107	6	144	8
Oceania	10	1	11	1	12	1	12	1
World	**1 705**		**1 740**		**1 785**		**1 862**	

Source: FAO, 2010a.

[a] Includes fuelwood, wood wastes, pellets, chips and other woody sources. A small volume of woodfuels may fall under other reporting categories and thus are not reflected here.

TABLE 14
Woodfuel use in selected regions

Region	Woodfuel consumption (m^3/1 000 persons)				Average annual rate of change, 1992–2007 (%)
	1992	1997	2002	2007	
Sub-Saharan Africa	804	797	726	766	-0.33
South America	543	529	524	510	-0.41
Asia	240	228	213	194	-1.41
Europe	163	145	149	203	1.45
Oceania	355	427	355	320	-0.69
World	**315**	**302**	**283**	**285**	**-0.67**

Source: FAO, 2010a.

complete burning. Mound kilns consist of an arranged pile of wood that is lit and covered by earth to reduce air flow. The efficiency of charcoal production in such traditional pits and mounds is low – about 20 percent of the original weight of wood is converted to charcoal and the remaining mass is released in the form of vapours and gases, including black smoke. A skilled charcoal producer who uses well-dried wood can reach efficiencies of up to 30 percent (Wiskerke, 2008). The species can also have an effect: slower-growing species with a high wood density are preferred, but in some species water is locked up so that it cannot be released by heating the wood, reducing the efficiency and quality of the charcoal. The age of the wood and its moisture content also influence quality and efficiency (Malimbwi, Zahabu and Mchome, 2007).

In modern kilns, about 35 percent of the original weight of wood can be converted to charcoal and the evolved gases and vapours flared to avoid local air pollution.

Globally, charcoal consumption increased by more than 50 percent between 1989 and 2008, with a large part of the increase in Africa, which accounts for more than half of all charcoal consumed (Table 15). Migration to urban and peri-urban areas has contributed to this expansion because charcoal is easier and cheaper to transport and trade than fuelwood. Charcoal production and transport are important sources of cash income in some rural and peri-urban areas; the economic value (real and/or perceived) of the charcoal industry is exemplified by the fact that it thrives even in many areas of sub-Saharan Africa, where there are many legal prohibitions against it.

Unlike in Africa, where the household use of charcoal is widespread, the expansion of charcoal use in South America and Europe has been largely for industrial purposes (FAO, 2010b). To some extent this is reflected in the changes in per capita use of charcoal shown in Table 16; in the period 1992–2007 per capita use increased moderately in sub-Saharan Africa (by 0.89 percent) compared with South America (3.12 percent) and Europe (1.6 percent). The use of charcoal as a substitute for fossil fuel can serve both economic and environmental goals, with carbon finance providing incentives for some small-scale industries to switch to charcoal.

TABLE 15
Average annual use of charcoal per five-year period, 1989–2008

Region	1989–1993		1994–1998		1999–2003		2004–2008	
	Volume *(Mt)*	Share of world total *(%)*	Volume *(Mt)*	Share of world total *(%)*	Volume *(Mt)*	Share of world total *(%)*	Volume *(Mt)*	Share of world total *(%)*
Africa	15.0	52	18.1	46	20.3	46	24.3	53
North America	0.5	2	0.8	2	0.9	2	0.9	2
South America	6.8	24	13.4	34	14.6	33	12.8	28
Asia	5.8	20	6.1	15	7.0	16	7.1	15
Europe	0.4	2	0.5	1	0.4	1	0.6	1
Oceania	0.0	0	0.0	0	0.0	0	0.0	0
World	**28.9**		**39.1**		**43.6**		**46.1**	

Source: FAO, 2010a.

TABLE 16
Per capita use of charcoal, selected regions

Region	Per capita charcoal consumption (kg per person per year)				Average annual rate of change, 1992–2007 *(%)*
	1992	1997	2002	2007	
Sub-Saharan Africa	25	27	26	28	0.89
South America	21	41	41	33	3.12
Asia	2	2	2	2	0.24
Europe	1	1	1	1	1.60
Oceania	1	1	1	1	-1.30
World	**5**	**7**	**7**	**7**	**1.94**

Source: FAO, 2010a.

There are significant differences in household charcoal use, even among countries with similar levels of economic development. For example, Zambia and Tanzania, two countries in Southern Africa, are among the highest per capita users of charcoal (71 and 65 kg per capita, respectively), whereas many West African countries have much lower per capita consumption (e.g. Ghana and Mali, 29 and 8 kg per capita, respectively) (NationMaster, 2010) because woody biomass is less available and/or other fuels have been promoted. Moreover, cultural and social preferences may be a factor.

FAO/22104/J. KOELEN

3. National, regional and global markets for woodfuels

This chapter presents an overview of woodfuel markets for key countries and regions, focusing on the predominant types of woodfuel. Globally, the international bioenergy trade has grown exponentially in recent years. In the case of solid woodfuels, the main commodities traded are fuelwood, wood waste, woodchips and wood pellets. The international trade in industrial roundwood also has implications for bioenergy use and trade, since further processing produces residues that can be used; regional shortages in industrial roundwood suggest that international trade in this commodity will increase in coming decades (Smeets and Faaij, 2007).

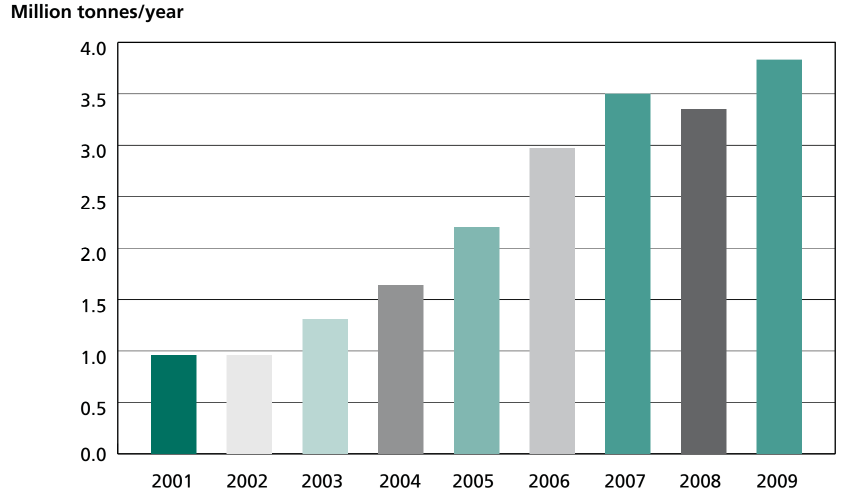
EUROPEAN UNION

The EU has specific policies to support renewable energy, and woodfuels have a central role. The policy goal is that renewable energy should constitute 20 percent of the EU's energy supply by 2020; it is expected that a significant part of this will be biomass-based (Pekska-Blanchard *et al.*, 2007). Currently about 5 percent of the energy consumed in the EU is derived from biomass (all sources); the main uses are in stand-alone biomass plants, co-firing with coal, and small-scale applications in households and small businesses.

The production of pellets began in a number of European countries as a way of using the abundant residues produced by sawmills – wood product industries are the largest source of woodfuels in Europe. Pellet production increased four-fold in the EU between 2001 and 2009 (Figure 1) and there is a fluid trade both within the EU and with external producers, particularly the Russian Federation and Canada (European Pellet Centre, 2010).

Germany, Sweden and Austria have the highest pellet production capacity, accounting for nearly half of total EU capacity in 2008 (Table 17). In 2008 the EU was a net importer of wood pellets. In the EU as a whole, production was 61 percent of total capacity, suggesting that market opportunities exist for those producers able to reduce costs to the extent necessary to compete with the major non-EU exporters. Interestingly, the country with the lowest average capacity, Italy, had the highest overall production capacity utilization; the main reason for this is that many Italian pellet producers are integrated with nearby sawmills, whereas in most other EU countries the pellet producers must source and contract their feedstock externally (European Pellet Centre, 2009). Integrated pellet producers face less uncertainty in feedstock supply and can generally control production and costs more easily.

FIGURE 1
Pellet production, EU



Source: European Pellet Centre, 2010

TABLE 17
Estimated wood pellet production and consumption in the EU, 2008

Country	No. of registered producers	Production capacity *('000 tonnes)*	Average capacity *('000 tonnes)*	Production *('000 tonnes)*	Capacity utilization *(%)*	Total consumption *('000 tonnes)*	Net (production minus consumption) *('000 tonnes)*
Austria	25	1 006	40.2	626	62	509	117
Finland	19	680	35.8	373	55	150	223
Germany	50	2 400	48.0	1 460	61	900	560
Italy	75	750	10.0	650	87	850	-200
Latvia	15	744	49.6	379	51	39	340
Poland	21	665	31.7	350	53	120	230
Sweden	94	2 200	23.4	1405	64	1 850	-445
Others	203	3 828	18.9	2 234	58	3 535	-1 301
EU total	**502**	**12 273**	**24.4**	**7 477**	**61**	**7 953**	**-476**

Source: European Pellet Centre, 2010

OTHER EUROPE AND THE RUSSIAN FEDERATION

Outside the EU the largest potential source of woodfuels in Europe is the Russian Federation, which has been an important supplier of biomass for energy to Western European markets for several years via its exports of roundwood for processing, primarily to Finland and the other Baltic states. Belarus and Ukraine have also developed pellet markets, with eight producers in Belarus and 15 in Ukraine as of the end of 2008 (European Pellet Centre, 2010). The primary source of raw material for wood pellet manufacture in those countries is sawdust. The export of raw roundwood from the Russian Federation is due largely to the relative underdevelopment of the Russian Federation forest and wood products sector. The Russian Federation already exports nearly 1 Mt of pellets per year (European Pellet Centre, 2010). Pellet production began in the mid-1990s using Soviet-era agricultural equipment and second-hand machinery imported from Europe (Pekska-Blanchard *et al.*, 2007).

NORTH AMERICA

North America has significant woodfuel potential. The United States of America has a large internal market, whereas Canada has a small domestic market and therefore looks to international markets to sell its surplus. Rapid growth and land-use pressures in Asia have opened up export markets for Canada's wood and wood products, particularly from the west coast, which has ready access to Asia. Mexico has significant forest resources for its size but these mainly supply the domestic market.

Canada

With one of the world's largest forest sectors and as a major exporter of lumber, Canada can be regarded as a biomass storehouse. In 2007–2008, for example, the country produced 21 million bone dry tonnes (Mbdt) of mill residue and had a surplus of 1.8 Mbdt, which is expected to increase substantially when the lumber market recovers from the recent downturn. There are also 21 Mbdt of bark in old mill piles, much of it in Quebec and Ontario, and nearly 10 Mbdt of urban wood waste (Bradley, 2009). The total Canadian forest resource designated as commercial growing stock stands at 40 billion m^3, the second-largest in the world after the Russian Federation (Pekska-Blanchard *et al.*, 2007; Bradley, 2009). Surplus woody biomass will also be available for energy over the next decade due to an infestation of the mountain pine beetle in pine forest in western Canada. It is estimated that, by 2012, 1 billion m^3 of wood will have been killed by the beetle in British Columbia alone (Bradley, 2009).

The wood products industry is declining in Canada in the face of international competition and the industry is looking increasingly to divert wood resources to energy, both for domestic use and export. Although Canada has renewable energy targets, growth in domestic demand for pellets and combined heat and power is slow; there is, therefore, an excellent opportunity for export. The production of wood pellets in Canada began in the late 1980s and has grown from around 0.5 Mt per year in 2003 to over 2.5 Mt in 2008, of which more than half was exported (Pekska-Blanchard *et al.*, 2007; Bradley, 2009). Canadian exports of wood pellets comprised more than 10 percent of EU consumption in 2008 (Junginger *et al.*, 2009).

United States

The woodfuel potential in the United States is smaller than that in Canada but the domestic market is considerably larger. There are various laws, executive orders and regulations to promote bioenergy. Presidential Executive Order 13101 (Greening the Government through Recycling and Waste Prevention) and Presidential Executive Order 13134 (Developing and Promoting Bio-based Products and Bioenergy) are good examples. It is likely that most biomass produced in the United States will be used domestically rather than exported. The wood pellet market has been expanding at a similar pace to that of Canada and amounted to 2 Mt in 2008 (Junginger, Sikkema and Faaij, 2009).

Mexico

Native tropical and temperate forests cover one-third of Mexico and biomass harvested from them provide about one-third of energy use in the country's residential sector. The current level of consumption is 18.4 megatonnes of dry matter (MtDM) of fuelwood and 3.2 MtDM of fuelwood-equivalent in charcoal; the technical potential for woodfuel production has been estimated at 55 to 59 MtDM annually (FAO, 2010b). Fuelwood is consumed by households for cooking, heating (in colder regions) and small cottage industries (e.g. brick and ceramics manufacture and blacksmithing). Charcoal is a significant source of energy; although produced in rural areas it is consumed primarily by urbanites and is therefore regarded mainly as a commercial activity. Fuelwood, on the other hand, is primarily non-commercial and is poorly captured in official statistics.

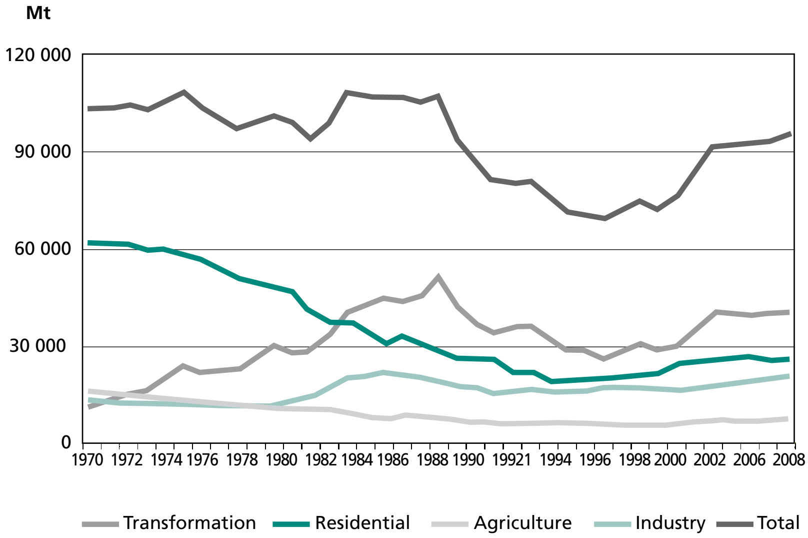
SOUTH AMERICA

Led by Brazil, South America has tremendous forest resources, although sustainable use for bioenergy is constrained by the important ecological and biodiversity values of the Amazon and other regions. Countries with the best-developed forest industries are Argentina, Brazil, Chile and Uruguay. The forest industries of some countries, such as Colombia, Ecuador, Guyana, Peru and Venezuela, are relatively underdeveloped for wood and energy production.

Brazil

Brazil has undergone a significant transition in the use of woodfuel in the past 20 to 30 years. This transition has some similarities with the typical shift away from biomass-based energy that has accompanied economic development in nearly all countries (often referred to as "climbing the energy ladder") but it also has some additional characteristics. As has occurred elsewhere, the residential use of fuelwood has declined with increasing affluence and urbanization. In contrast to many other countries, however, declining residential use has been offset by significant increases in charcoal use for industrial applications (Figure 2). The upsurges in usage in the 1980s and mid 2000s were both linked to significant expansions in pig-iron production (FAO, 2010b). The industrial-sector use of charcoal accounts for 90 percent of charcoal consumption in Brazil, of which about two-thirds is used in pig-iron production.

FIGURE 2
Woodfuel consumption in Brazil, by sector



Source: EPE, 2009

Wood used for charcoal production is increasingly sourced from forest plantations rather than native forests; in 1990, 60 percent of Brazilian charcoal production was from native forests and 40 percent from plantations but, by 2008, the share of native forests had decreased to 36 percent (IBGE, 2009). In 2005 there were 5.4 million hectares of forest plantations in Brazil; in addition to being used for charcoal, a large part of these plantations is devoted to wood-pulp production. Energy use from residues and surpluses typically amounts to 10 to 15 percent of the total biomass supply (World Resources Institute, 2008).

Brazil is becoming a major player in international bioenergy trade. Increasing exports of biomass from plantation forests offer possibilities for improving the efficiency of the pulp and paper industry. It is estimated that 50 million m^3 of forestry residues are produced annually but are generally not used for energy (Walter, Dolzan and Piacente, 2006).

Argentina and Chile

In 2002 Argentina had 2 230 sawmills producing 94 million m^3 of wood (Rodriguez, 2006) and yielding 4 to 5 Mt of unused wood waste. There are also several million tonnes of waste forestry biomass on river banks that could easily be exported (IEA Bioenergy Task 40, 2009).

Chile's forest industry is about one-third the size of Brazil's. In 2007, Chile manufactured 60 000 tonnes of wood pellets and exported 20 000 tonnes. The long distances to major markets, coupled with old port facilities, make pellet exports a challenge. Given cheap shipping rates and the fact that pellets have a lower transport cost per unit energy than liquid biofuels, Chile could nevertheless become a significant bioenergy exporter (Chadwick, 2006; Bradley, 2009).

SUB-SAHARAN AFRICA

Africa has 16 percent of the global forest area, compared with Europe's 25 percent, but a greater mass of aboveground woody biomass (Table 18). Brief comments on the woodfuel production potential of South Africa, Mozambique and Tanzania are given below.

South Africa's forest plantation area (1.35 million hectares in 2000) exceeds its natural forest area (0.5 million hectares in 2000) (FAO, 2005). The small natural-forest area is due more to natural climatic conditions than the deforestation of a formerly large indigenous resource. Because the country has relatively good infrastructure, woodfuels in the form of woodchips and pellets are being exported by a number of companies.

Mozambique has the tenth-largest forest area in Africa but, unlike South Africa, does not have a large wood-processing sector, producing just 38 000 m^3 of sawnwood annually. Nevertheless, it has been identified as a country with large potential for bioenergy exports because of its favourable climate, long coastline and large land area. Mozambique has 30 million hectares of forest and 50 million hectares of agricultural area, of which less than 5 percent is currently used; there are only 38 000 hectares of planted forest (FAO, 2006b). The country has several Indian Ocean ports, such as Maputo, Beira and Nacala, with rail-links to the country's interior and some regional destinations, which would facilitate international trade in woodfuels.

Over 90 percent of Tanzania's energy is derived from wood. Tanzania has a total forested area of 35 million hectares, the fifth-largest in Africa, and about 150 000 hectares of planted forest. At a national level it is estimated that the mean annual increment of Tanzania's forests (67 million m^3 of solid wood) exceeds total demand (45 million m^3) (TATEDO, 2005). However, regional surpluses and shortages of wood exist and a significant proportion of wood use is likely to be unrecorded. Deforestation is a serious issue in Tanzania; the main causes have been

TABLE 18

Comparison of European and African woody biomass resources

Region	Forest area, 2005		Above-ground biomass, 2005		Roundwood production, average 2000–2002		Pulpwood and sawnwood, average 2000–2002		Woodfuel, average 2000–2002	
	Million ha	% of global total	Mt	% of global total	Million m^3	% of global total	Million m^3	% of global total	Million m^3	% of global total
Europe	1001	25	71	18	581	17	306	35	105	538
Africa	635	16	96	25	605	18	19	2	6	30

Source: FAO, 2006a; Hillring, 2006.

cited as woodfuel use (including charcoal), agriculture (shifting cultivation) and forest fire. The annual deforestation rate is estimated to be in the range 100 000 to 500 000 hectares per year (Abdallah and Monela, 2007).

Tanzania has a sizable wood-processing industry and a number of sawmills. An estimated 944 000 m^3 of domestic sawnwood was consumed in 1998, implying that a similar quantity of residues could be made available for energy use. The forest sector accounts for around 10 percent of Tanzania's exports, mostly through the port of Dar es Salaam, which handles 95 percent of Tanzania's international trade (Tanzania Ports Authority, 2007). Forest residues from plantation operations are usually used for fuelwood or, in some cases, for generating heat and power. Residues from the wood-processing sector are less commonly used for energy and there is scope for increasing bioenergy use in the forest sector.

ASIA

Historically, Asia is the continent with the greatest use of woodfuels, in many diverse applications. The recent economic boom in many Asian countries has caused a sharp decline in woodfuel use followed by a revival. The two largest markets are China and India, but the Indonesian, Philippine, Thai and Vietnamese markets are also significant. The wood products and bioenergy sectors have been criticized as unsustainable and often leading to deforestation and desertification.

China

The transformation of the Chinese economy, with its rapid industrialization and integration into the world economy, is having a profound effect on the use of woodfuels. Given the large internal differences between rural and urban dwellers, however, such effects are uneven. In the short to medium term it is difficult to predict the extent of this massive transformation away from traditional biomass use and its impacts on woodfuel consumption and supply.

The Chinese Government has a proactive policy to develop renewable energy, of which bioenergy is a top priority, focusing on electricity generation. The target is 30 gigawatts of biomass-based electricity generation by 2020, which will require many new stand-alone biomass plants in addition to co-firing with coal. China has plans to produce 50 Mt of pellets by 2020 (Pekska-Blanchard *et al.*, 2007).

China is the world's largest consumer of coal. In addition to the generation of electricity, coal is used in many applications both at an industrial scale and in small heating appliances and cooking stoves, some of which are highly inefficient. About 48 percent of the coal consumed in 2002 (720 Mt) was in thermo-boilers, which could be partially replaced by woodchips or wood pellets, representing a potentially huge market (Pekska-Blanchard *et al.*, 2007).

India

India is the world's largest user of woodfuels (including fuelwood, twigs, branches and residues), primarily in traditional applications. Fuelwood is an integral part of the informal economy and is used primarily in rural areas by households, cottage industries and restaurants, and for cremations. The daily use of fuelwood by households is estimated to account for 90 to 95 percent of total consumption (FAO, 2010b). India's rapid development and urbanization, and the increasing penetration of electricity in rural areas, has brought about a shift towards other forms of energy. Nevertheless, many of India's poor still use woodfuels because they are "free".

There is a lack of long-term reliable data on woodfuel use in India, as surveys are carried out infrequently or not at all (for example, there is no regular survey of wood consumption in cottage industries, hotels or restaurants). According to a recent study (FAO, 2010b) about 60 percent of Indian households (75 percent of rural households and 21.7 percent of urban households) used woodfuels in 2005, for a total consumption of 248 million m^3. The average monthly per capita consumption was 17.7 kg in rural areas and 6.3 kg in urban areas. The volume of fuelwood estimated to be taken from forests per year is about 50 million m^3, or 20 percent of total annual consumption; the remainder is sourced from farmland, community land, homesteads, roadsides, canal-sides and various types of "wasteland" that include abandoned agricultural areas (FAO, 2010b).

Oceania

The Australian economy and energy sector is dominated by fossil fuels (coal, natural gas and oil) and, until recently, renewables have played a minor role. According to official statistics, the share of total energy consumption of all renewables combined was just 5 percent (285 petajoules [PJ]) in 2006–2007. Of this, wood waste provided 93 PJ and bagasse 101 PJ; the supply of all biomass in the same year was 200 PJ (ABARE, 2009). Australia's large woodfuel potential in the form of native forests, timber waste and plantations is beginning to be recognized.

Given its significant forest resources relative to population, New Zealand has a natural comparative advantage when it comes to bioenergy production. Its estimated annual production of woody biomass from forest plantations is 4 to 6 Mt, the equivalent of about 10 percent of national energy demand. The wood-processing industries also generate a significant amount of wood waste, which is only partly used. In 2006 there were five wood pellet plants with a total annual production capacity of 100 000 tonnes. Woodfuels have considerable potential for further expansion in New Zealand (Pekska-Blanchard *et al.*, 2007).

Other Asia

Given the size of its energy market, Japan is an important potential user of woodfuels in East Asia. An import market is taking shape, with demand stimulated by legal incentives to promote renewable energy in Japan. The 2002 Biomass Nippon Strategy, for example, foresees a considerable increase in the use of biomass as an energy source (IEA, 2009a).

4. Future trends in energy, climate and woodfuel use

In this chapter the scope for future woodfuel use is placed in the context of expected trends in energy markets in the next 10 to 20 years. General global trends are reviewed in reference to past energy consumption and future projections developed by the International Energy Agency (IEA, 2009a). The IEA reference scenario provides a forecast of global energy use by fuel, region/country, sector and application; it assumes no fundamental changes in existing energy/climate policies and institutions and is based on an array of assumptions concerning the cost and availability of fuels, market structures, technologies and distribution/transport infrastructure.

HISTORICAL ENERGY TRENDS

Global primary energy demand increased by 37 percent between 1990 and 2007 (Table 19), while power generation increased by 52 percent (Table 20). The strong demand for electricity, particular in China, is the main reason for a significant increase in coal consumption; renewables increased at a higher rate but from a much lower base. The use of biomass and waste for power generation increased at a faster rate than the overall use of biomass as a source of primary energy, mainly because as the use of biomass for power generation has increased its use for traditional purposes has declined. The cost-effectiveness of biomass for heat and power generation in Europe and North America has been the main driver of increasing demand for biomass energy, along with the financial incentives available for renewable energy in the EU and several other regions.

TABLE 19
Global total primary energy demand

Energy type	Demand (EJ)		Share of total demand (%)		Annual average change (%)
	1990	2007	1990	2007	
Coal	93	133	25.4	26.5	2.43
Oil	135	171	36.7	34.1	1.61
Gas	70	105	19.1	20.9	2.75
Nuclear	22	30	6.0	5.9	2.01
Hydro	8	11	2.1	2.2	2.46
Biomass and waste	38	49	10.3	9.8	1.77
Other renewables	2	3	0.4	0.6	4.92
Total	**367**	**503**			**2.13**

Source: IEA, 2009b.

Trends in overall energy demand can also be assessed according to the status of countries as either Annex I or non-Annex I parties based on their obligations under the United Nations Framework Convention on Climate Change (UNFCCC). Energy demand in non-Annex I parties, led by China and India, nearly doubled between 1990 and 2007, resulting in a major shift in global energy-use patterns; non-Annex I parties now account for half of global energy use (Table 21). This transition in global energy demand has implications for woodfuels and other energy sources because the energy infrastructure in Annex I parties is older and suited for different fuels than the infrastructure in non-Annex I parties. For example, the co-firing of biomass in coal plants is more easily accommodated at the stage of boiler design and installation rather than in retrofitting (IEA, 2009a).

Energy consumption trends in Annex I and non-Annex I parties illustrate some of the sectoral dynamics of demand across end-use sectors at different phases of economic development (Table 22 and Table 23). The mature economies of Annex I parties have experienced greatest demand growth in service-oriented sectors ("other consumers" in the tables), where much of the demand is for electricity. Growth in non-Annex I demand has been greatest in industry and construction, where various fuels are used. Energy demand in the household

TABLE 20

Global primary energy demand for power generation

Energy type	Demand *(EJ)*		Share of total demand *(%)*		Average annual change *(%)*
	1990	**2007**	**1990**	**2007**	
Coal	51	91	41.2	47.6	3.86
Oil	16	12	12.6	6.2	-1.85
Gas	24	41	19.3	21.7	3.66
Nuclear	22	30	17.6	15.6	2.01
Hydro	8	11	6.2	5.8	2.46
Biomass and waste	2	4	2.0	1.8	2.38
Other renewables	1	3	1.1	1.3	4.28
Total	**125**	**191**			**2.87**

Source: IEA, 2009b.

TABLE 21

Global total primary energy demand by Annex I and non-Annex I parties

Group	Total primary energy demand *(EJ)*		Share of global demand *(%)*		Change *(%)*
	1990	**2007**	**1990**	**2007**	
Non-Annex I	128	250	35	50	4.6
Annex I	239	252	65	50	0.4
Total	**367**	**503**			**2.1**

Source: IEA, 2009b.

TABLE 22
Final (delivered) energy demand by sector, Annex I parties

Sector	Demand *(EJ)*		Share *(%)*		Average annual change *(%)*
	1990	2007	1990	2007	
Agriculture	1	1	1.6	0.9	1.10
Households	11	25	24.5	26.1	5.68
Industry and construction	11	27	25.6	28.0	5.86
Other consumers	3	16	5.7	16.3	12.92
Transportation industry	19	27	42.6	28.7	2.49
Total	**44**	**95**			**5.23**

Source: Calculated from IEA, 2010a.

TABLE 23
Final (delivered) energy demand by sector, non-Annex I parties

Sector	Demand *(EJ)*		Share *(%)*		Average annual change *(%)*
	1990	2007	1990	2007	
Agriculture	1	2	2.5	1.7	3.1
Households	23	33	56.0	34.5	2.6
Industry and construction	7	38	18.5	39.8	11.5
Other consumers	5	12	13.0	12.9	6.2
Transportation industry	4	11	10.0	11.1	6.6
Total	**40**	**97**			**6**

Source: Calculated from IEA, 2010a.

sector has grown fastest in Annex I parties, largely because households there mainly use electricity; households in non-Annex I parties are using mainly traditional forms of biomass energy, which are less versatile and therefore less given to rapid consumption increases.

PROJECTIONS OF ENERGY SUPPLY AND DEMAND TO 2030

The IEA reference scenario provides "a baseline picture of how global energy markets would evolve if governments make no changes to their existing policies and measures" (IEA, 2009a). It shows an annual growth in energy demand through 2030 of 1.5 percent (Table 24), with coal consumption growing at an annual rate of 1.9 percent annually. It is projected that oil consumption will rise by 0.9 percent annually, mainly in non-OECD countries. Natural gas use will expand by 1.5 percent annually, with the Near East, China and India as major consumers along with North America, the Russian Federation and Europe. Coal consumption will grow at 1.9 percent annually, mainly due to rising consumption in China (IEA, 2009a).

Electricity consumption is expected to increase by 1.9 percent annually to 2030, with over 80 percent of the growth in non-OECD countries. Nuclear power capacity will be added in all OECD regions except Europe, and also in China and India. Biomass for power generation grows at 5 percent in the reference scenario, which is lower than the "other renewables" category, which grows at 7.4 percent (Table 25) (IEA, 2009a). However, since these figures are for primary energy and only electricity (i.e. they do not include heat), it is important to note the difference in measurement for thermal power compared to other renewables. The high share of coal for electricity production illustrates a potential role for biomass co-firing. For new power plants, climate change mitigation options include biomass cogeneration (heat and power) plants where scale and resources can be matched to demand.

TABLE 24
IEA reference scenario: total world primary energy consumption

Energy type	Primary energy consumption *(EJ)*			Share of total *(%)*		Average annual change, 2007–2030 *(%)*
	2007	2020	2030	2007	2030	
Coal	133	173	205	27	29	1.9
Oil	171	186	210	34	30	0.9
Gas	105	127	149	21	21	1.5
Nuclear	30	36	40	6	6	1.3
Hydro	11	14	17	2	2	1.8
Biomass and waste	49	60	67	10	10	1.4
Other renewables	3	9	15	1	2	7.2
Total	**503**	**605**	**703**			**1.5**

Source: IEA, 2009b.

TABLE 25
IEA reference scenario: world primary energy for power generation

Energy type	Primary energy consumption *(EJ)*			Share of total *(%)*		Annual average change to gross consumption, 2007–2030 *(%)*
	2007	2020	2030	2007	2030	
Coal	91	120	146	48	49	2.1
Oil	12	8	7	6	2	-2.3
Gas	41	50	61	22	21	1.7
Nuclear	30	36	40	16	14	1.3
Hydro	11	15	17	6	6	1.8
Biomass and waste	4	7	11	2	4	5.0
Other renewables	3	8	13	1	4	7.5
Total	**191**	**244**	**295**			**1.9**

Source: IEA, 2009b.

GLOBAL CO_2 EMISSIONS

According to the IEA reference scenario, global energy related CO_2 emissions are expected to increase from 29 gigatonnes of carbon (GtC) per year to 40 GtC per year between 2007 and 2030 (Table 26). Under the IEA reference scenario, energy-related CO_2 emissions are dominated by power generation and transport, with increases of 50 percent and 40 percent, respectively, between 2007 and 2030. Transport-sector emissions are overwhelmingly from road transport. One difficulty in relating the IEA projections to substitution potential lies in the incomplete nature of data on heat consumption and heat demand. Since cogeneration has the most cost-effective substitution potential, it is difficult to estimate the real achievable potential.

The calculation of CO_2 emissions and greenhouse gas impacts associated with bioenergy is plagued by a number of uncertainties, most of which are poorly addressed in current accounting methods. First, land-use change due to bioenergy production is not necessarily included; in some cases it may be accounted for within the applicable land-use sectors, although there are considerable uncertainties associated with above-ground versus below-ground biomass. Second, the uncertainty in data on traditional biomass use results in corresponding uncertainties in emissions, even if conversion assumptions are reasonably accurate. Third, the use of traditional forms of biomass energy gives rise to black carbon or soot, which is not a global greenhouse gas but which does increase radiative forcing. Since the Intergovernmental Panel on Climate Change

TABLE 26
Energy-related CO_2 emissions for IEA reference scenario (Gt C)

Sector	1990	2007	2020	2030
Power generation	7 471	11 896	14 953	17 824
Other energy sector	1 016	1 437	1 755	1 993
Industry	3 937	4 781	5 571	6 152
Iron and steel	938	1 470	1 702	1 796
Non-metallic minerals	505	818	822	810
Other industry	2 493	2 493	3 047	3 546
Transport	4 574	6 623	7 733	9 332
Road	3 291	4 835	5 646	6 920
Aviation	538	742	884	1 067
International shipping	358	613	685	780
Other transport	387	433	518	564
Residential	1 891	1 877	2 031	2 198
Services	1 066	878	972	1 096
Agriculture	405	433	423	437
Non-energy use	581	900	1 087	1 195
Total	**20 941**	**28 826**	**34 526**	**40 226**

Source: IEA, 2009b.

(IPCC) does not yet include "short-lived" climate forcers such as black carbon, these impacts are not reflected in accounts (Bond and Sun, 2005).

ENERGY AND ELECTRICITY ACCESS

Also of importance for future emissions and the scope of woodfuel use is the projection of the number of people without access to electricity in the reference scenario, since this determines the number of people reliant on traditional biomass use. The total number of people reliant on traditional biomass use globally is expected to decrease by 175 million between 2008 and 2030 (Table 27). In some countries and regions, particularly in sub-Saharan Africa, however, the absolute number will increase. Moreover, these figures represent only those people who will have no access to electricity, nearly all of whom will be in rural areas. There is an additional number of people, almost as great, who will have limited or unreliable access to electricity and this group also uses traditional biomass in significant quantities. Sub-Saharan Africa is expected be the only major world region where electricity access will remain below 50 percent in 2030.

WOODFUEL CONSUMPTION

Mead (2005) analysed the role of planted forests in providing woodfuels and used regional statistics of current woodfuel use to project woodfuel use to 2030 (Table 28). Consumption is expected to decrease in Asia, mainly due to shifts in China and India. Total woodfuel consumption in 2030 is projected to be 1 502 million m^3, which equates to 15 to 18 EJ. The projections for Europe appear to be too low, since EU legislation is stimulating greater wood energy use (European Commission, 2006, 2009).

TABLE 27

Access to electricity, IEA/WEO reference case

Region	**2008**				**Projections**			
	Population without access ***(millions of people)***	**Electrification rate** ***(%)***			**Population without access** ***(millions of people)***		**Electrification rate** ***(%)***	
		Overall	**Urban**	**Rural**	**2015**	**2030**	**2015**	**2030**
Africa	589	40	67	23	627	700	45	54
North Africa	2	99	100	98	2	2	99	99
Sub-Saharan Africa	587	29	57	12	625	698	36	47
Non-OECD Asia	809	77	94	67	764	561	80	87
China	8	99	100	99	5	0	100	100
India	405	65	93	53	385	294	69	79
Other	396	63	85	48	374	267	68	81
Latin America	34	93	99	70	18	13	96	98
Near East	21	89	98	71	11	5	95	98
World	**1 456**	**78**	**93**	**63**	**1 422**	**1 281**	**80**	**84**

Source: IEA, 2009b.

TABLE 28

Actual and projected woodfuel consumption, by region (million m^3 per year)

Region	**Actual**		**Projected**	
	1990	**2005**	**2020**	**2030**
Asia	852	740	630	550
South Asia	336	369	362	339
East Asia	283	205	155	127
Africa	365	463	526	545
South America	96	104	115	122
North and Central America	170	167	142	162
Europe	127	122	104	96
World	**1 612**	**1 605**	**1 558**	**1 502**

Source: Mead, 2005.

Future woodfuel use will also be determined by the quantity of woody biomass that can be sustainably supplied for modern bioenergy use. One set of estimates for 2050 shows a supply range of up to 100 EJ, based on various combinations of residues and surplus forest growth, after accounting for future demand for industrial roundwood and fuelwood (Smeets and Faaij, 2007). The imposition of stringent ecological and economic criteria reduces this potential to as low as zero; nevertheless there is considerable scope for increasing the sustainable use of forest resources for woodfuels by improving forest and wood product management (Smeets and Faaij, 2007).

FAO/FO-6071/M. TROSSERO

5. Climate change mitigation potential of woodfuels

This chapter reviews some of the options for greenhouse gas mitigation using woodfuels, focusing on the costs incurred in relation to the carbon that is saved or substituted under various bioenergy systems. A brief summary of the costs of such systems is given, followed by comments on the measurement of greenhouse gas impacts. Selected greenhouse gas mitigation measures that rely solely or primarily on woodfuels are presented in later chapters. In general, mitigation occurs when woodfuels substitute for fossil fuels or where there is greater efficiency in the application of biomass technology.

The measures reviewed here are not intended to be exhaustive; nor do they cover all sectors or applications, although in general they encompass the main short-term options. The site-specific nature of bioenergy means that such estimates cannot easily be extended or applied in specific contexts; therefore, they are representative only of the overall options within a sector and do not necessarily point to any particular project portfolio that might be pursued. The final chapter gives some national-level examples on a portfolio basis in order to provide a sense of how a set of measures or programmes might be applied in a given country.

COSTS OF BIOENERGY SYSTEMS

Given the many options available, the cost of bioenergy systems cannot easily be summarized in the way in which other renewables, such as wind and solar, can be. Table 29 presents investment costs for stationary applications of commercial systems using combustion or gasification for heat ($MW/kW_{thermal}$) and power ($MW/kW_{electrical}$).

In some cases, costs are expected to come down considerably once large-scale systems are commercialized. Note that performance changes with the quality of biomass supply; for example, in some cases the incineration of waste wood results in lower efficiency due to the considerable variation in the combustion properties of wastes and the difficulty of controlling for variations during operation.

The feedstock cost depends on a variety of site-specific factors such as labour costs, transportation costs and the availability of logistical infrastructure. One set of estimates for the EU for 2010 showed costs for residues ranging from €2.1 to €3.1 per GJ and from €1.8 to €3.7 per GJ for woody crops grown in forest plantations (Hansson and Berndes, 2009). The delivered cost will be considerably lower in most developing countries due to low labour costs but logistics and transport will tend to be uncertain and/or more expensive. An analysis in Tanzania estimated costs ranging from US$0.53 to US$1.46 per GJ (€0.43 to €1.18 per GJ

TABLE 29

Summary of estimated efficiencies, costs and deployment of bioenergy systems

Process or method	Applications	Capacity range	Net efficiency (lower heating value)*(%)*	Investment cost	Deployment status
Combustion					
Heat	Domestic (modern furnace)	1–5 MW$_{th}$	65–90	300–700 €/kW$_{th}$	Increasing use of modern furnaces and prepared biomass (pellets)
Combined heat and power	District heating, industrial uses	1–10 MW$_{e}$	80–100 (system)	1500–2000 €/kW$_{e}$	Widely deployed in Europe and North America
Stand-alone	Waste incineration	20–100s MW$_{e}$	20–30 (electrical)	2000–2500 €/kW$_{e}$	Low efficiency for mass burning/ incineration
	High-efficiency designs	20–100s MW$_{e}$	30–40 (electrical)	1500–2000 €/kW$_{e}$	Widely used in northern Europe
Co-firing	Existing coal plants	5–20 MW$_{e}$	30–40 (electrical)	~250 €/kW$_{e}$ + cost of existing plant	Widely deployed
Gasification					
Heat	Small-scale	<1 MW$_{th}$	60–90 (system)	200–600 €/kW$_{th}$	Commercially deployed
Combined-heat-and-power gas engine	Small-scale	<1 MW$_{e}$	15–30	1000–3000 €/kW$_{e}$	Limited deployment
Biomass gasification combined-cycle		30-100 MW$_{e}$	40–50	5000–6000 €/kW$_{e}$	Demonstration phase at smaller scales
		30-100 MW$_{e}$	40–50	1000–2000 €/kW$_{e}$	Large-scale (long-term)

Source: Adapted from Faiij, 2006.

Notes: kW$_{e}$ = kilowatts$_{electical}$; kW$_{th}$ = kilowatts$_{thermal}$; MW$_{e}$ = megawatts$_{electrical}$; MW$_{th}$ = megawatts$_{thermal}$

at current exchange rates) for fuelwood, from either woodlots or managed areas (Wiskerke *et al*., 2010).

These costs compare quite favourably with the price of steam coal in the IEA reference scenario of US$70 to $100 per tonne (€1.9 to €2.7 per GJ, assuming hard coal at 29.7 GJ per tonne). In the case of co-firing at coal plants, the woody biomass feedstock can be compared directly. Under stand-alone comparisons, however, the investment costs will be considerably lower for coal and therefore there will need to be other considerations or other sources of support based on factors such as carbon finance, a preference for smaller scale or, in the case of imported coal, concerns about energy security.

GREENHOUSE GAS IMPACTS, LAND USE AND CARBON SEQUESTRATION

The mitigation potential of woodfuels is based on two main factors: the substitution of biomass for fossil fuels, and the sequestration of carbon in standing biomass. The main constraint that arises for substitution is the lower energy content of biomass compared to fossil fuels. This results in much higher transport costs which, together with variations in the quality of biomass, increases the uncertainty of biomass supply for a given energy production facility. It also provides the logic behind charcoal markets: the higher energy content of charcoal makes wood biomass a more tradable commodity because of its lower transport cost per unit energy. In many regions of Africa, the price of charcoal tends to vary little in relation to the distance it has travelled because, to a considerable extent, markets internalize the transport costs, as is common for internationally traded commodities (Johnson and Rosillo-Calle, 2007).

Carbon sequestration is based on the type of biomass and soils, the level of biological activity, and other physical and climatic factors. In the absence of losses, bioenergy is carbon-neutral, since the carbon released on combustion is taken up in the next cycle of the plant or tree growth. However, losses can occur in the supply chain and losses from soil and root systems can occur as a result of land-use change.

The greenhouse gas impacts of bioenergy are necessarily based on the entire lifecycle, from planting through harvesting, transport and end-use. A detailed greenhouse gas balance for specific cases is beyond the scope of this study, and the balances used here should be regarded as representative only. Land-use impacts are generally not included in these estimates, although for those options where residues are used the land-use impacts will generally be minor. The large-scale cultivation of bioenergy crops using agroforestry can have significant implications for the greenhouse gas balance where land is cleared or otherwise severely disrupted (Schubert *et al.*, 2009). Alternatively, the soil properties of marginal lands can improve under a careful management regime.

BIOMASS-BASED ELECTRICITY GENERATION

The potential for biomass power plants depends on factors such as the available biomass supply, the minimum scale required, alternative uses of the biomass, and the geographically closest fossil-fuel competitors, which will generally be natural gas or coal. Biomass is most competitive where there is sufficient demand for heat to allow for combined heat and power production (cogeneration); in such cases the overall system efficiency can be as high as 80 to 90 percent. Biomass gasification systems can also be competitive with natural gas, although this is uncertain in the short term due to high investment costs. The IPCC's Fourth Assessment Report (IPCC, 2007) reviewed estimates for biomass electricity generation and developed a categorization according to the abatement cost, as shown in Table 30.

At current carbon prices of US$10 to $20 per tonne, somewhat less than half of the potential should be achievable; moreover, the potential is concentrated in non-OECD countries where there are opportunities for the Clean Development Mechanism (CDM) and other financial mechanisms. This is the technological/economic potential, however, and does not necessarily take into account the various issues related to implementation, deployment, infrastructure and especially the reliability of biomass feedstock supply, which almost always depends on local conditions.

TABLE 30

Estimated 2030 mitigation potential and abatement cost for bioelectricity generation

Countries	Total emissions that can be saved in 2030 *($GtCO_2eq$)*	Mitigation potential by cost per tCO_2eq avoided *(%)*			
		<US$0	US$0–20	US$20–50	US$50–100
OECD	0.20	20	25	40	15
Economies in transition	0.07	20	25	40	15
Non-OECD	0.95	20	30	45	5
World	**1.22**				

Source: IPCC, 2007.

BIOMASS CO-FIRING

Co-firing woody biomass in coal-fired power plants is a widely available and cost-effective option. Within the EU, the potential has been estimated at 0.5 to 1 EJ per year in the short term (the higher end of the range assumes use even in plants that are more than 40 years old) (Hansson *et al.*, 2009). As shown in Table 31, it has been estimated that the overwhelming majority of cost-effective abatement using co-firing is in China because of the large number of coal-fired plants that have been built there in recent years – it is easier to introduce biomass to newer plants compared with older plants. However, cost goes up over time; it more than doubles in China between 2015 and 2030 as the most cost-effective options are implemented.

In general, securing feedstock supply and ensuring proper operation are the key considerations for biomass co-firing, especially at older power plants. It should be noted that non-woody biomass as well as waste might also be used for co-firing. In some cases such sources will be cheaper, but the relatively clean characteristics of woody biomass reduce the potential for fouling the boiler equipment, additional maintenance costs and other operational problems.

BIOMASS SUBSTITUTION AT STEEL PLANTS

There is also potential for biomass substitution in the iron and steel industries, where charcoal can replace coking coal. This potential is much smaller than in power plants due to the quantities involved and the location-specific nature of such industries. The costs, however, are negative, since biomass is cheaper than coking coal. In some regions, especially Brazil, large quantities of charcoal are already used for steelmaking; the potential in these regions is therefore limited. Nevertheless, the potential role of woody biomass in the iron and steel industries is large at the global scale; since all biomass is expected to be sourced locally, the estimates in Table 32 do not consider charcoal trade and are therefore underestimates.

IMPROVED CHARCOAL PRODUCTION OPTIONS

Although not yielding large greenhouse gas savings in global terms, improving the efficiency of charcoal production offers local benefits by improving the delivery of

TABLE 31
Greenhouse gas abatement and cost for biomass co-firing in coal-fired power plants

Region	**Abatement** *(MtC)*		**Cost** *(US$/tonne C)*	
	2015	**2030**	**2015**	**2030**
United States	47.0	39.2	33.3	42.7
EU (selected)	20.5	20.3	22.8	23.0
Russian Federation	20.1	14.1	3.9	10.7
Japan	6.3	6.4	48.6	47.7
China	329.0	218.0	10.2	25.8
India	37.8	14.5	8.8	50.3
South Africa	4.3	3.4	35.4	49.7
Others (total)	64.0	48.5		
World	**529**	**364**	**15**	**30**

Source: McKinsey and Company, 2009.

TABLE 32
Abatement by and costs of biomass substitution for coking coal at steel plants

Region	**Abatement** *(MtC)*		**Cost** *(US$/tonne C)*	
	2015	**2030**	**2015**	**2030**
United States	0.6	0.9	-6.6	-6.7
Brazil	0.6	0.9	-9.2	-9.1
Rest of EU27	0.9	1.3	-6.2	-6.3
Russian Federation	0.7	1.1	-10.5	-10.6
Japan	1.3	1.9	-6.4	-6.5
China	7.8	12.2	-11.9	-11.6
India	1.0	1.7	-9.2	-9.2
South Africa	0.1	0.2	-6.4	-6.5
Others (total)	2.9	4.4	-	-
World	**15.8**	**24.6**	**-9.8**	**-9.7**

Source: McKinsey and Company, 2009.

energy services, reducing impacts on health and the environment, and saving money. In some countries, improved charcoal production is a low or negative cost measure that compares well with other mitigation options (see section on Conservation and woodfuel mitigation actions and Table 36). A wide range of technologies is available for charcoal production, from simple earth kilns to complex, large-capacity charcoal retorts.

Improved charcoal production technologies are aimed largely at increasing the efficiency of charcoal production as well as at improving the quality of the charcoal. Improved charcoal kilns can be classified into five categories: earth kilns, metal kilns, brick kilns, cement or masonry kilns, and retort kilns. These are differentiated mainly by their technical sophistication and investment cost. Table 33 shows the main characteristics of each of the five categories.

The more complex designs are less labour-intensive and include semi-automated operations. In addition, by-products in the high-cost designs are often just as important as, and sometimes more important than, the charcoal produced. The low-cost, simpler designs are particularly suitable for developing countries, where labour is usually abundant.

While most of the low-cost improved charcoal kilns have demonstrated high efficiencies under test conditions, none has been substantially disseminated, largely because of the nature of charcoal production in many developing countries and the surprisingly high efficiency of traditional kilns under field conditions. Earth kilns were once thought to be a grossly inefficient technology, but a 1984–1985 study in Sudan indicated that their efficiency was comparable with improved brick and metal portable kilns. Table 34 shows the efficiency of various low-cost kilns.

The critical factors in determining the efficiency of traditional designs appear to be operational skill and the moisture content of the utilized wood. The

TABLE 33
Main characteristics of various categories of charcoal kilns

Kiln type	Typical capacity	Yield *(%)*	Cost *(US$)*	Where used
Earth				
Mound	5–100 m^3	10–25	Very low	Many developing countries
Casamance	Variable	25–31	200	Cameroon, Ghana, Malawi and Senegal
Pit	3–30 m^3	30–35	Very low	Sri Lanka, United Republic of Tanzania and other developing countries
Metal				
Mark V	300–400 kg	20–25	2 000–5 000	Uganda
Oil drum	12–15 kg	23–28	Low	Kenya, the Philippines
Brick				
Beehive and half-orange	9–45 kg	25–35	150–500	Argentina, Brazil and Malawi
Cement or masonry				
Katugo	70 kg	25–30	8 000	Uganda
Missouri	350 kg	25–33	15 000	United States and other developed countries
Retort				
Cornell	1–3 tonnes	22–33	40 000	Norway and other developed countries (smaller prototypes tried in Ghana and Zambia)
Lamboitte	3 000–20 000 tonnes per year	30–35	0.5 million – 2 million	Australia, France, Côte d'Ivoire and other developing countries

Source: UNCHS, 1993.

TABLE 34

Conversion efficiencies of earth and pit kilns

Kiln type	Percentage recovery, oven-dried wood	Percentage recovery, air-dried wood
Casamance earth kiln	31	27
Metal channel earth kiln	29	25
Modified metal channel kiln	25	21
Earth mound kiln (control)	25	21
Pit kiln	15	13

Source: UNCHS, 1993.

presence of a chimney that ensures optimum draught conditions also appears to be important.

A large proportion of charcoal production in developing countries is carried out as a semi-illegal, part-time activity – the wood used is often procured illegally. Consequently, few charcoal-makers are willing to invest in improved charcoal kilns because of the risk of punitive official measures and taxes. Consequently, dissemination of improved charcoal techniques to the informal sector has proved difficult. Improved charcoal production technologies have been more successful in areas where production is undertaken on a commercial basis, such as in Malawi.

Another area where the cost-effectiveness of charcoal, and its energy efficiency, can be improved is in transportation. Given charcoal's fragility, excessive handling and transporting over long distances can increase the amount of fines to up to 40 percent, greatly reducing its economic value. Distribution in bags helps to limit the production of fines and also provides a convenient, measurable quantity for both retail and bulk sales.

TRADITIONAL BIOMASS: IMPROVED COOKING STOVES

With more than two billion users of traditional biomass worldwide, the energy savings and emission reductions potential of improving the efficiency of cooking stoves is enormous. Another factor is the sustainability of the biomass resource: harvesting that exceeds the maximum that can be regenerated in a given region has been labelled "non-renewable" under the CDM and has been subject to greater limitations in carbon finance. Calculating the emission reductions from improved management requires the estimation, verification and monitoring of the biomass supply, but data are normally difficult to obtain.

Estimates of emission reductions from improving the efficiency of traditional cooking stoves are uncertain, since the underlying data are either unavailable or subject to considerable fluctuation. The number of users and the types of equipment and their energy consumption are not well known. Thus, the estimates shown in Table 35 have a wide range. The estimates of costs include only those related to the cost of the stove and fuel; neither other costs nor emission reductions from improved forest management are considered.

TABLE 35

Estimated emissions abatement from improved cooking stoves

Country/region	Abatement *(Mt C)*		Cost *(US$ per tonne of carbon)*	
	Low	High	Low	High
India	33	150	-1	6
Sub-Saharan Africa	52	190	-3	4
Other Asia/Pacific	29	67	-1	8
Other Americas	11	52	-	-
Total	**125**	**459**		

Source: Bhattacharya and Jana, 2009; Bhattacharya, 2009; Bond and Sun, 2005.

TABLE 36

Mitigation options analysed in forest and woodfuels sectors, Mexico

Interventions	Area *(million ha)*	Mitigation *($MtCO_2eq/yr$)*	Investment *(US$ million)*	Net cost/benefit *($US\$/tCO_2eq$)*
With negative cost/benefit ratio				
Efficient charcoal production	2.8	11.3	416	-20
Forest management	9.0	4.2	148	-13
Improved stoves		10.0	434	-2
Biomass electricity (wood-based)	12.0	17.1	11 250	-2
Subtotal	**23.8**	**42.5**	**12 248**	
With positive cost/benefit ratio				
Fuelwood co-firing	0.1	2.0	454	7
Afforestation	1.6	7.0	1 084	8
Reforestation and restoration	4.5	7.7	2 229	9
Wildlife management	30.0	9.8	169	18
Payment for environmental services	5.0	2.3	923	18
Subtotal	**41.1**	**28.7**	**4 859**	
Total	**64.9**	**71.2**	**17 187**	

Source: Johnson *et al.*, 2009.

CONSERVATION AND WOODFUEL MITIGATION ACTIONS

Recently, expectations have been raised about payments for reduced deforestation, improved forest management, afforestation and forest restoration and forest conservation activities through carbon credits for REDD-plus ('reduced emissions from deforestation and forest degradation' plus conservation, sustainable management of forests, enhancement of forest carbon stocks). In some circumstances the potential income from carbon credits under bioenergy options will outweigh the income from REDD options. One study in Tanzania found that the mean annual increment was too low to make carbon sequestration through forestation a profitable exercise under the CDM, but short-rotation woodlots provided employment and were cost-competitive in the supply of a bioenergy feedstock (Wiskerke *et al.*, 2010). In such semi-arid regions, small-scale bioenergy production could be a useful way to earn carbon credits (as a fossil-fuel offset) while also improving energy services.

In a national context, woodfuel options tend to compare favourably with land management options aimed at conservation. In Mexico, an evaluation of various forest-based climate change mitigation options found that, in some cases, bioenergy options had a negative cost/benefit ratio (i.e. the benefits outweighed the costs); conservation options tended to be more costly because there was less certainty of a stable revenue stream than in the case of a marketable commodity (Table 36).

FAO/FO-7006/A. PERLIS

6. Socio-economic impacts

Woodfuel has a wide range of uses, ranging from use in traditional cooking stoves, to co-firing with coal, to dedicated biomass power plants (including combined heat and power). The socio-economic impacts of woodfuel use vary depending on a range of factors including the country, feedstock and end use. This section summarizes the likely social, economical and livelihood impacts of biomass use at various scales.

HEALTH IMPACTS

In many African households, the use of woodfuels for cooking is a major source of indoor air pollution. The inefficient and incomplete combustion of woodfuels releases a number of hazardous pollutants, including carbon monoxide, sulphur and nitrogen oxides, and particulate matter. In many households, poor ventilation exacerbates the effects of these pollutants, and women and children are often exposed to them at significant levels for 3 to 7 hours each day (Bruce, Perez-Padilla and Albalak, 2002). Such prolonged exposure has been implicated in an increased incidence of respiratory disease.

The causal relationship between high concentrations of particulate matter and acute respiratory infections (ARIs) has been established in a number of studies and is reviewed thoroughly in Smith *et al.* (2000a). Accounting for an estimated 10 percent of disease-related deaths in Africa (Bruce *et al.*, 2002), ARIs pose a major threat to women and children in developing nations. Children are particularly susceptible to acute lower respiratory infections (ALRIs), a specific type of ARI; ALRIs are the leading cause of death among children younger than five (Bruce *et al.*, 2002). A study by Ezzati and Kammen (2001) of 55 rural Kenyan households that relied primarily on fuelwood and charcoal quantified the exposure–response relationship between the incidence of ARI and the indoor concentration of particulate matter, showing it to be a concave curve that increases with exposure. The potential to reduce exposure – and, by proxy, ARIs – is significant: a follow-up study (Ezzati and Kammen, 2002) found that a complete transition to charcoal as a feedstock would reduce the incidence of ARIs by up to 65 percent. Cleaner cooking fuels offer the potential for even greater reductions. Gas-burning stoves, for example, emit up to 50 times fewer pollutants than biomass-burning stoves (Smith *et al.*, 2000b); the incidence of ARIs in Africa would likely drop considerably as a result of a major shift towards the use of gas-burning stoves.

Several other diseases have been attributed to exposure to indoor air pollution from solid-biomass fuels. Smoke produced in the combustion of fuelwood, for example, deposits carbon in the lungs and is known to cause chronic bronchitis, emphysema and chronic obstructive pulmonary disease. Several studies have also linked childhood exposure to fuelwood smoke with asthma, although others have concluded that there is no association between the two.

SOCIAL IMPACTS OF WOODFUEL COLLECTION AND USE

IEA (2006) reported that the average load of fuelwood in sub-Saharan Africa was 20 kg. The task of collecting fuelwood has become increasingly onerous as deforestation and forest degradation have increased the distances that must be travelled to obtain sufficient supply. In addition, fuelwood collection in remote and politically unstable areas poses significant safety risks to women. The amount of time spent and distance travelled in the collection of fuelwood vary between regions, but most studies have found that women spend a significant portion of their days collecting fuelwood. A survey of 30 households near Lake Malawi, for example, found that the mean distance to a viable fuelwood resource was 2.1 km, the average trip time was 241 minutes and the average time spent collecting wood per day was 63 minutes (Biran, Abbot and Mace, 2004). A study of three villages in northern Kenya suggested that women there spent an average of 70 minutes per day collecting fuelwood (McPeak, 2002). In Tanzania, the roundtrip distance for fuelwood collection varied from just over 1 km to 10.5 km (IEA, 2002).

In developing countries the use of woodfuel from residues and by-products is an additional consideration in some non-industrial plantings. Farmers seldom plant trees solely for fuelwood: rather, fuelwood is often a secondary product. The woody biomass may be used in a variety of forms (e.g. twigs, stems, branches and leaves) and may also come from a range of sources, such as natural and planted forests, trees outside forests, and shrublands (Mead, 2005).

The main socio-economic concerns related to the use of biomass for energy include labour conditions and land-related issues (Table 37). Some initiatives to develop standards for biomass production and use include social criteria. A number of international bodies, including the OECD and the EU, are actively looking at the potential of biomass. The use of biomass and by-products for energy purposes should consider economic, environmental and social sustainability and develop future policies and market approaches. International standards and codes of practice can help maximize the environmental benefits (ADAS, 2006).

Most forest certification schemes (see Chapter 8) address biodiversity conservation, soil management (including the application of fertilizers and pesticides), water management and land tenure. Land tenure has important implications for the production of liquid biofuels in some developing countries.

ECONOMY: LOCAL AND REGIONAL LINKAGES

Markets for biomass for energy are developing rapidly and becoming more regional and international. The trading of biomass has increased significantly in recent years (IEA, 2009a).

The PISCES project (Practical Action Consulting, 2009) used case studies in developing countries to examine market developments at a regional level that might help to promote the sustainable use of biomass. In Senegal, for example,

TABLE 37
Potential socio-economic impacts of biomass production and use

Phase of production or use	Potentially adverse impacts	Potentially beneficial impacts
Biomass production (farm)	Health and safety – e.g. pesticide application, use of harvesting machinery Freedom of association and collective bargaining Working hours and remuneration/ benefits Migrant labour Child/forced labour Land ownership/access to land Food security – quantity and price Access to water resources Land/water contamination and associated health implications Impacts on landscape Foreign control and imbalance of economic benefit Community and cultural dilution	Rural employment and income generation Infrastructure development Economic leakage
Biomass/fuel transport (road/sea)	Frequency/ intensity of access Conflict over land tenure – road building Local health impacts from transport emissions Potential for marine spills – impacts on local industry and landscape	
Biomass pre-treatment and conversion (factory)	Health and safety – machinery risk, fire safety, contamination and hazardous substances Working hours and remuneration/ benefits Discrimination/abuse Child/forced labour Foreign control and imbalance of economic benefit	Rural employment and income generation Infrastructure development Economic leakage
Residue disposal	Land/water contamination and associated health implications	

Source: PricewaterhouseCoopers, 2006.

access to fuelwood for cooking is constrained by a reduction in quotas for biomass energy production and a reduction in forest area. A government–private-sector initiative called PERACOD in the city of Saint-Louis is manufacturing char briquettes from recycled low-value charcoal dust, boosting the local economy and reducing deforestation. Over a period of eight months (November 2007 to June 2008) the initiative produced about 18 000 kg of briquettes, of which 15 000 kg were sold, giving the company a turnover of around €2 850. This is a significant enterprise in the city, which is marked by high unemployment.

COMMUNITY MANAGEMENT OF COMMERCIAL WOODFUELS

Two community-based approaches of relevance to the sustainable use of woodfuels are community-based woodfuel production (CBWP) and forest replacement associations. Both address commercial woodfuel production to supply large markets – where the potential for forest degradation and ultimately deforestation is high. CBWP engages communities in forest management on community-owned or publicly owned lands, a common land-tenure category in parts of sub-Saharan Africa, whereas forest replacement associations engage private farmers in forest management on privately owned lands, which is common in Latin America.

After nearly 20 years of experience in transferring forest management rights to local populations, CBWP has proven the feasibility of the sustainable production of woodfuel; in case studies in Niger and Senegal, for example, a considerable annual increase in the forest stock was achieved after local communities assumed responsibility for the management of their forest resources. The results from forest replacement associations in several Latin American countries have been mixed but, on average, positive (ESMAP, 2010).

7. Environmental impacts

The use of biomass for energy production poses various potential threats to ecosystems and the services they provide. Harvesting that leads to the degradation or loss of native forests, will have other negative impacts on a number of parameters including, biodiversity, soil stability and water quality and quantity. Nevertheless, a sustainable forest management regime and the sustainable use of woodfuels can enhance and even improve the delivery of some ecosystem services – providing local emission control, increasing water availability, improving biodiversity and enhancing habitats and landscapes.

This chapter explores the potential impacts of woodfuel production and use and opportunities for sustainable use.

BIODIVERSITY

The unsustainable extraction of forest resources, such as for woodfuel, may lead to forest degradation and permanent loss of biodiversity. Globally, over one-half of the temperate broadleaf and mixed forest biome and nearly one-quarter of the tropical rainforest biome have been fragmented or removed by humans. Nevertheless, the establishment of dedicated woodfuel plantations and sustainable and community-based forest management can reduce the negative impacts of woodfuel production and even restore and enhance biodiversity.

A classic example of a positive outcome from woodfuel plantations is the Green Belt Movement in Kenya. This started in 1977 as a tree-planting programme to address deforestation caused by woodfuel gathering and the conversion of land for agriculture; today it is a movement for women-empowering, community-based reforestation and forest management to provide a sustainable woodfuel resource and enhance soil fertility for agriculture. To date, the Green Belt Movement has planted more than 40 million trees throughout Africa, contributing to the restoration of native vegetation, the development of biodiversity corridors and the protection of habitats.

Another good example of community-based management is in Madagascar, where the World Bank and the national government launched a five-year CBWP in 1992 for both forest production and the protection of the country's unique biodiversity. The approach involved the creation of contracts for the management and sustainable use of forest areas to community-based institutions. In 2000, over 500 contracts had been issued throughout Madagascar, involving about 500 000 hectares of forest and contributing to biodiversity conservation through the protection of corridors and key habitats. The project was successful in achieving biodiversity conservation goals; however, conservation interests were often imposed over the commercial interest of communities to distribute woodfuel –

without adequate compensation mechanisms for the environmental services the communities were providing. In 2008 the Government of Madagascar prohibited all forest exploitation in the country; however, there remains a high demand for woodfuel and a black market has developed, jeopardizing the work of the CBWP project (ESMAP, 2010).

Plantations can have both positive and negative impacts on biodiversity. Generally the biggest impact is due to the change in land use (ADAS, 2006). Biodiversity is likely to increase if the woodfuel crop is replacing introduced pasture or annual agricultural crops, and decrease if it is planted on land with high species diversity, such as unmanaged wetlands or native forests (Woods *et al.*, 2006). When woodfuel plantations are established, therefore, the initial land use is crucial in determining the impact on biodiversity. The choice of tree species can also have an effect: native species are likely to accommodate more of the native biodiversity. A buffer zone between a woodfuel plantation and established woodland or hedgerows can help to preserve edge habitat important for a diversity of species. Woodfuel plantations can also provide corridors between isolated natural habitats. Overall, careful planning and judicious siting of woodfuel plantations within a landscape can enhance biodiversity (Woods *et al.*, 2006).

Weed control is essential during the establishment of woodfuel plantations, but once the crop is mature the growth of a ground flora can have a range of beneficial effects on biodiversity. Ground cover encourages the presence of invertebrates, which in turn can lead to an increase in the presence of small mammals and birds (DEFRA, 2002). The timing of harvesting is another factor; in some climates, harvesting in early summer can affect breeding populations and in winter can remove shelter and food resource (ADAS, 2006).

AIR QUALITY: EMISSIONS AND CYCLES

Even where traditional biomass is harvested sustainably, woodfuel use may not be carbon neutral due to incomplete combustion – the idealized fuel cycle in which all carbon is converted to carbon dioxide is unrealistic. Instead, due to incomplete combustion, carbon is released in other forms, including methane, nitrous oxide, carbon monoxide and non-methane hydrocarbons. These compounds are referred to as products of incomplete combustion (PICs) and have much higher global-warming potential than carbon dioxide. According to the IPCC (2007), the 100-year global-warming potentials of methane and nitrous oxide are 25 and 298 times that of carbon, respectively. Because of the incomplete combustion of woodfuels, between 10 and 20 percent of the carbon released is in the form of PICs (Smith *et al.*, 2000b). The molar ratio of PIC emitted to total carbon emitted is defined by researchers as the k-factor of a fuel; it varies depending on the technology used to burn the fuel. Alternative cooking fuels typically have much lower k-factors than woodfuel (Table 38).

The potential to reduce carbon emissions in sub-Saharan Africa by shifting to clean cooking fuels is significant. Aside from their low k-factor, fossil fuels have several other advantages over woodfuels: a higher energy density, a higher nominal

TABLE 38
K-factors for various cooking fuels

Fuel	K-factor
Woodfuel	0.1–0.2
Kerosene (wick stove)	0.051
Kerosene (pressure stove)	0.022
LPG	0.0231
Biogas	0.00562

Source: Smith *et al.*, 2000b.

combustion efficiency, and a higher heat transfer efficiency. These factors offset their higher carbon density, as both LPG and kerosene produce less carbon per unit of useful energy than woodfuel. At the same time, because the k-factor is lower, even less of the carbon is released as PICs.

Given an unsustainable pattern of woodfuel extraction, in some cases a transition to petroleum-based fuels could reduce net carbon emissions. Emission scenarios based on this shift (to a combined use of kerosene and liquefied petroleum gas (LPG) to meet household cooking needs) project a decrease in cumulative emissions by 2050 of 1 to 10 percent (Bailis, Ezzati and Kammen, 2005). It is worth noting, however, that if woodfuels were produced sustainably and used with greater efficiency the associated carbon emissions would generally be less than those associated with petroleum-based fuels.

Notable potential impacts of woodfuel processing and energy production include emissions such as dust or fly ash that could affect sensitive plant species such as lichens, and the emission of dioxins and metals (depending on the combustibles used). Air-quality regulations could be used to control a range of such emissions (Scottish Natural Heritage, 2007). Biomass-based power plants could conceivably emit higher levels of nitrogen oxides, ammonia and particulate matter than some conventional power plants (e.g. oil and gas). Emissions of sulphur dioxide, on the other hand, tend to be lower. The disposal of waste products, such as ash, involves additional transport emissions and may create other environmental problems (Scottish Natural Heritage, 2007).

A heat-producing plant needs a local heat-distribution network to service its customers. This usually means the construction of the plant reasonably close to housing or commercial or industrial premises that can make use of the heat. The Royal Commission on Environmental Pollution (RCEP, 2004) recommended paying particular attention to emission control, for reasons of both public and environmental health and public acceptability. A modern wood-burning plant should be able to meet all air pollution control standards at a reasonable cost. In particular it is important that biomass plants are not located in areas where they would exacerbate existing poor air quality.

WATER: IMPACTS AND POLLUTANTS

Water availability

Poorly conducted, woodfuel harvesting can have significant effects on water quality and quantity, leading, for example, to increased soil erosion and run-off. On the other hand, forest plantations can require fewer fertilizers and pesticides than annual agricultural crops, thus reducing the risk of water pollution. In addition, forest root systems help to filter pollutants in surface water.

In some cases, forest plantations use less water than annual agricultural crops, but this is highly dependent on the species used and management regime imposed. Fast-growing, short-rotation forest plantations use more water than plantations composed of slower-growing species. Because of their large leaf area, willow and poplar, for example, intercept more rainfall than agricultural crops, reducing the amount of water reaching the soil and recharging aquifers or nearby surface water. In addition, they have high transpiration rates and deep root systems. As a result, willow and poplar short-rotation crops use more water than annual agricultural crops and can also tap into underground water in times of low rainfall (Woods *et al.*, 2006). The environmental impacts of such high water use are site-dependent: in areas of low rainfall or where there is high human consumption of water (e.g. the south east of England), for example, it could cause water shortages and lower the water table. On the other hand, it may be useful in reducing excess runoff and can help mitigate local flooding, even in low-rainfall areas. The effects of short-rotation forest plantations on hydrology should be evaluated through location-specific analysis that includes the species grown, soils, topography, and rainfall and management practices (RCEP, 2004; IEA, 2008).

The high water requirement of willow may constrain its use to areas where sufficient irrigation water is available (RCEP, 2004). Sewage or sewage sludge can be used to irrigate willow and will also provide additional nutrients (although the high heavy-metal content of sewage can potentially pollute the soil). Willow can be used to reduce soil contamination by absorbing heavy metals, but this, in turn, may affect the composition of the ash following the combustion of the wood.

Water quality

On good land, short-rotation forest plantations are likely to increase water quality compared with land used for agriculture because of its lower agro-chemical requirements. There is some evidence that, in particular locations, the application of fertilizers and sewage sludge can cause nitrate leaching. However, it has also been suggested that mixtures of trees and grasses used as bioenergy crops could be cultivated along waterways to act as buffers, limiting nutrient runoff from agricultural land (Woods *et al.*, 2006).

SOIL: NUTRIENTS, AGRONOMY, TOPOGRAPHY

Forest plantations for woodfuel remain in place for a number of years, establish good root systems, and develop leaf litter layers, all of which helps to conserve or promote soil fertility and prevent soil erosion. When harvesting forest residues for bioenergy, site-specific considerations should take into account the unique qualities of both the soil and the topography to avoid soil-related damage, especially on low-fertility sites (Mead, 2005). Large areas of open ground are exposed during the establishment of a forest plantation, leaving the site vulnerable to wind erosion (especially on light, sandy soils) and water erosion (especially on sloping sites during rain events).

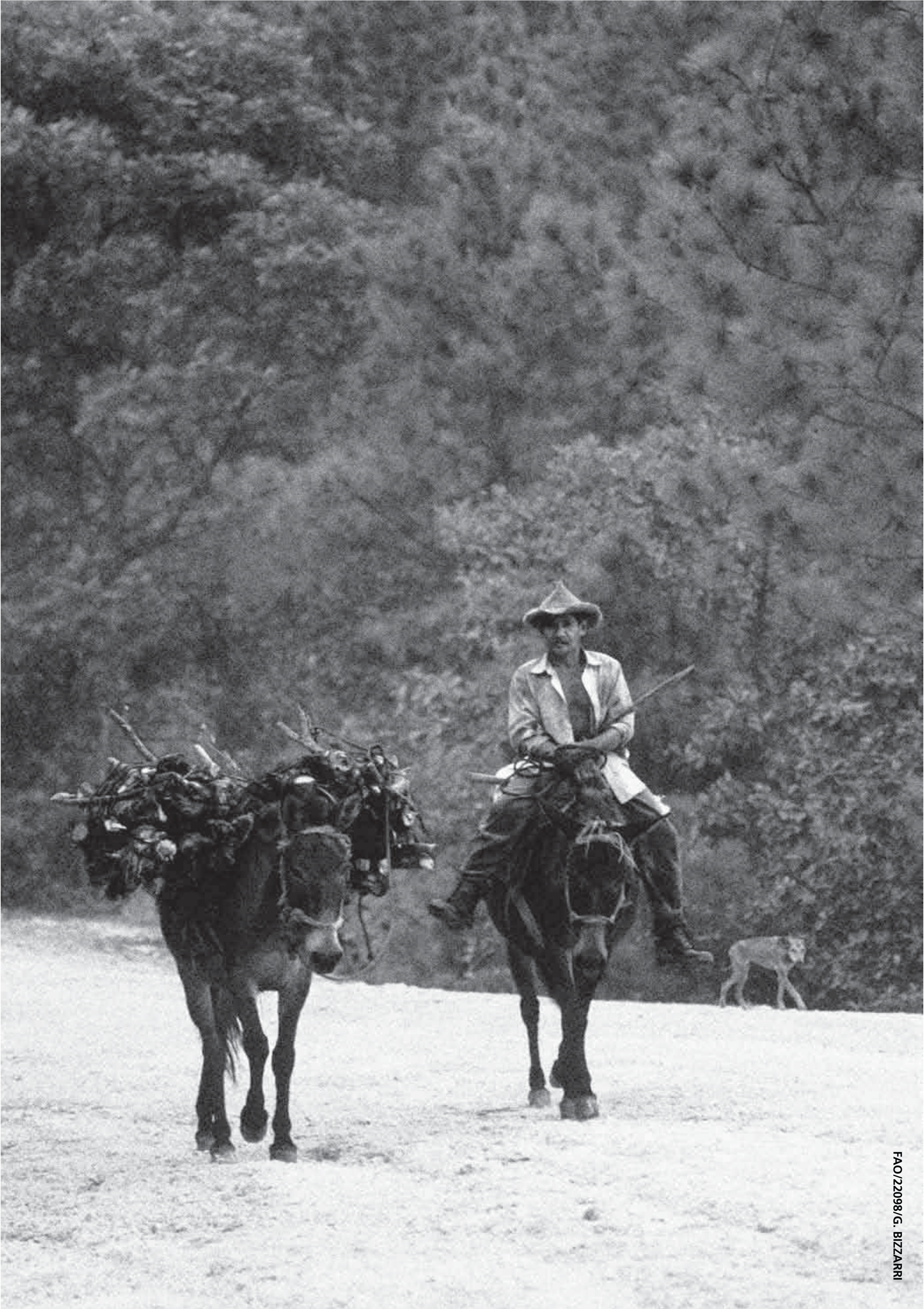
Harvesting should aim to minimize nutrient removal and physical damage to the soil. Ideally, most of the nutrient-rich foliage will be retained on the site. Minerals such as calcium, magnesium and, to a lesser extent, potassium and phosphorus, are contained in the bark of eucalypts and some other hardwoods. According to Santana, Barros and Comerford (2000), leaving the bark on site is a good nutrient conservation practice for eucalypt plantations in Brazil. Another common practice is to return the ash generated by combustion to the site to help compensate for the loss of nutrients caused by biomass removal. Nevertheless, this is not fully achieved and some sites need additional fertilizers (Mead, 2005). Harvesting machinery should be chosen carefully to minimize soil damage and avoid erosion.

A set of ten principles has been developed for nutrient management in woodfuel production with the aim of assisting foresters to strike a balance between production, ecological services and carbon management (IEA, 2008). The principles include the idea of a strong commitment to adaptive forest management, which requires continual monitoring and adjustment (Raison, 2002).

MARKET IMPACTS

The forest industry has the capacity to absorb some additional demand from the growing bioenergy sector, at least in the short to medium term (20 years). In particular, wood pellets, woodchips and other residues (the largest traded resources) originate mostly from by-products, residues and waste (including sawdust and other residues from the forest industry). In the last few years this resource has expanded in northern countries (e.g. Canada, the United States, Sweden and Norway) but it is still largely under-used in developing countries and thus there is considerable scope for expansion. Being largely a waste resource, such an expansion would require no additional land or other resources (such as water), and there may be positive economic outcomes for local forest industries. In some cases, however, an emerging woodfuel export industry may stress existing transport infrastructure.

Of concern is the potential impact in areas where there is little existing formal forest industry. In Mozambique and Tanzania, for example, there is no well-established forest industry from which residues could be obtained and woody biomass still supplies over 80 percent of domestic energy. The development of an international bioenergy market could have serious impacts on those domestic markets; the export of biomass from such countries requires careful assessment of its impacts.



FAO/22098/G. BIZZARRI

8. Sustainability certification

As a renewable energy source, woodfuels can be carbon neutral, but assuring their sustainability requires careful socio-economic and environmental management along the entire supply chain. The aim of sustainable forest management is to ensure the long-term availability of forest resources while also maintaining ecosystem services such as soil and watershed protection; it encompasses the administrative, legal, technical, economic, social and environmental aspects of the conservation and use of forests. Sustainable forest management implies various degrees of deliberate human intervention, ranging from actions aimed at safeguarding and maintaining a forest ecosystem and its functions, to those favouring specific socially or economically valuable species or groups of species for the improved production of goods and services.

Interest in the international bioenergy trade has grown quickly in the last decade. The fastest growth has been primarily in woodchips and pellets – mostly from forest-sector and agricultural residues – traded at the national, regional and global levels. Bioenergy has traditionally been produced and consumed locally and thus its international trade is a recent phenomenon; given its potentially large scale, however, the sustainability of production is increasingly of international concern.

Environmental criteria for bioenergy production have been devised both for agricultural crops (e.g. the Roundtable for Sustainable Palm Oil) and forest-based systems (e.g. the Forest Stewardship Council and the Rainforest Alliance). They include:

- biodiversity (including genetically modified organisms) and natural ecosystems;
- water (efficient use and conservation, and pollution);
- soil conservation;
- crop management (e.g. the use of fertilizers and pesticides);
- waste management.

A number of schemes exist for the certification of forest management; they have broadly similar criteria and standards. The Rainforest Alliance, for example, is a certification body accredited by the Forest Stewardship Council; its Smartwood scheme has generic standards for assessing forest management and general standards for any type of crop management (Rainforest Alliance, 2007). The Forest Stewardship Council standards have been adapted to accommodate national and regional differences (Forest Stewardship Council, 2006a, 2006b). There are Forest Stewardship Council-accredited national initiatives in Brazil, Burkina Faso, Cameroon, Canada, China, Côte d'Ivoire, Hungary, Japan, Poland, Romania, the Russian Federation, Slovakia, South Africa, Zambia, and most

Western European countries. There are also a range of other standards, such as the chain-of-custody standard (FSC-STD-40-004).

Conservation International has developed a standards system for land-based projects that can deliver climate, biodiversity and community benefits, probably the most comprehensive of all standards related to the use of biomass (including for energy). The system describes quantitative and qualitative indicators and the ways of measuring them; in particular it addresses carbon stocks, which are not well covered by other certification and standards systems. The system has been tested in Asia, Africa, Europe and the Americas (CCBA, 2005).

An International Organization for Standardization (ISO) system is yet to be established for biomass, biofuels and energy, although there are standards for agriculture and forestry that may well be applicable. Life-cycle assessment is a way of quantifying the total environmental impact of a feedstock from production to final disposal. ISO 14040 describes an approach to life-cycle assessment based on an energy analysis framework (ISO, 2006). ISO has also developed a standard, ISO 14064, for greenhouse gas accounting and verification with the aim of providing governments and industry with an integrated set of tools for programmes aimed at reducing greenhouse gas emissions, as well as for emission trading. With the increasing market demand for biomass for biofuels and bioenergy production, a certification system is clearly needed. The World Wide Fund for Nature (2006) has called for an eco-certification system for biofuels in Europe, not only for those produced internally but also for those imported.

In Europe, the pan-European forest criteria and indicators for sustainable forest management have been in use since 1995; some of the indicators are of a qualitative nature and others are quantitative.

Other forest certification systems used in Europe which consider biomass production are those of the Forest Stewardship Council and the Green Gold Label (Junginger, 2006). The latter has three sections: a general standard; a forest standard; and an agricultural standard. All apply to agricultural or forest biomass and products and related industries. The main value of the general standard is the inclusion of a chain of custody for products involving transport, quality control and administration. The indicators in the Green Gold Label are similar to those of the ISO 9000 series, which reviews the administrative process. Forest management criteria require verifiable information, but they are mainly descriptive and fail to provide clear instructions on measurement.

The ten principles of the Forest Stewardship Council are as follows:

1. Compliance with laws and Forest Stewardship Council principles;
2. Tenure and use rights and responsibilities;
3. Indigenous peoples' rights;
4. Community relations and workers' rights;
5. Benefits from the forest;
6. Environmental impact;
7. Management plan;
8. Monitoring and assessment;

9. Maintenance of high-conservation-value forests;
10. Plantations.

The Forest Stewardship Council principles could be applied to all types of feedstock. Principle 1 (on legal compliance), for example, refers to the laws of the country or region, international treaties, and the Forest Stewardship Council's own principles. It encompasses international agreements related to biodiversity (such as the Convention on the International Trade in Endangered Species of Wild Fauna and Flora and the Convention on Biological Diversity), as well as those related to social issues, such as the International Labour Organization.

In many ways the most contentious principle is Principle 2 on tenure rights; it specifies that "clear evidence of long-term forest use rights to the land (e.g. land title, customary rights, or lease agreements) shall be demonstrated" (Forest Stewardship Council, 1996). In many developing countries, this is problematic; nevertheless, it is not an insurmountable problem, as suggested by the significant area of forest certified by the Forest Stewardship Council in developing countries (Table 39).

There is a risk that the use of a single system of certification could become simply a bureaucratic procedure involving the filling in of a form rather than a process to properly verify the sustainability of the management and use of resources (including waste) for energy production. A system like that proposed by the United Kingdom's Low Carbon Vehicle Partnership, which would involve a meta-standard, may be preferable. A meta-standard would work through a cross-compliance framework involving the development of "supplementary checks" to address gaps in existing schemes (ECCM, 2006).

Forest certification schemes that have generic standards for assessing forest management may also be applicable to woodfuels and other biofuels. For example, importing countries are now demanding assurances of the sustainability of imported biofuels across the production chain; this could have a major impact on the development of bioenergy markets. There are developments in forest certification that take into account aspects such as the reduction of greenhouse gas emissions, the preservation of biodiversity, non-competition with food supply, and ensuring the social and economic wellbeing of workers (e.g. ensuring the essential rights of workers, health benefits, and minimum wages). There is no "perfect fuel"; thus, some requirements may be complicated to implement in practice.

As a consequence of the Renewables Energy Directive (European Commission, 2009), sustainability standards are being considered for solid biomass to match those for liquid biofuels. Nevertheless, currently there is no date for the publication of standards for solid biomass. The European Committee for Standardization (CEN) T383 group continues to develop a sustainability CEN standard for Europe and is considering one for solid biomass.

In many cases, international forest certification systems such as the Programme for the Endorsement of Forest Certification and the Forest Stewardship Council could be applied to woodfuel production. These schemes contain environmental and socio-economic criteria and indicators that can be used to monitor and assess

TABLE 39
Certified forest area, 2000 (all schemes) and 2010 (FSC only) ('000 ha)

Region	2000 (all schemes)	2010 (FSC only)
Asia (excluding Near East)	158	3 247
Latin America and Caribbean	1 978	10 394
Europe	46 703	54 705
North America	30 489	48 876
Oceania	410	1 500
Africa	974	6 777
Annex I	77 562	102 200
Non-Annex I	3 155	23 248
World	**80 717**	**125 448**

Source: World Resources Institute, 2008; Forest Stewardship Council, 2010.

various aspects of the production chain as well as institutional issues such as the effectiveness of legislation and guidelines overseeing woodfuel production. They focus primarily on forests managed for timber production, although some of these practices clearly will have spin-off impacts that affect sustainability when bioenergy is also a major priority.

Table 39 provides information on forests certified under all schemes in 2000 and for FSC only as of March 2010. Certifications by ISO 14001 are not included because they are not designed specifically to assess whether sustainable forest management is being applied. Other certification bodies include the American Tree Farm Program, the Canadian Standards Association, Green Tag, and the Sustainable Forest Initiative of the American Forest and Paper Association. The area of certified forests increased considerably between 2000 and 2010, although it remains overwhelming concentrated in Europe and North America. As of March 2010, the area certified by the Forest Stewardship Council alone represented a 50 percent increase over all types of certification in 2000.

9. Carbon finance for woodfuels

Carbon finance involves investments in greenhouse gas emission reduction/ avoidance projects and the creation of financial instruments that are tradable on a market. Three market-based mechanisms exist within the Kyoto Protocol: emissions trading, joint implementation (JI) and the Clean Development Mechanism (CDM). There is also an active voluntary carbon market, the Voluntary Carbon Standard (VCS) programme. Institutions such as the World Bank, the European Investment Bank, Agence Française de Développement and the Japan International Cooperation Agency invest in climate change mitigation projects through carbon markets as well as within the framework of JI and the CDM. Brazil, India and Mexico are eligible for the CDM but not JI.

CLEAN DEVELOPMENT MECHANISM

The CDM allows countries included in Annex B of the Kyoto Protocol to carry out projects in developing countries to obtain certified emission reduction (CER) credits as part of efforts to meet their emissions targets. Establishing additionality is one of the most important requirements for the acceptance of a project under the CDM; that is, it must be shown that the emission reductions would not have occurred without the CDM project.

To be validated, a proposed CDM project must use an approved baseline and monitoring methodology (UNFCCC, 2010); if no approved methodology is applicable the project developer can propose a new methodology. Table 40 summarizes approved methodologies related to woodfuels.

Asia, particularly India and China, dominates CDM investments, with more than 60 percent of total investments; Latin America is in second place with around 25 percent of total investments. Reasons for the skewed distribution of projects may include the stability of the governments and economies of those regions, and the level of industrial development, which makes it easier to use existing methodologies without the need for complicated adaptations or the development of new methodologies.

WOODFUELS IN THE CDM – CASE STUDIES

According to the register of CDM projects, approximately 600 projects at various stages (from registered to issued) are directly or indirectly related to woodfuels. They are mainly in the following six areas: co-firing generation of electricity; power generation with biomass; switch from fossil fuels to biomass; switch from fossil fuels to wood-based pellets; ethanol production; and direct combustion of woody biomass. The great majority of these projects are in Asia or Latin America. Below, three cases in which woodfuels are used in different processes are described. Table 41 compares these and other projects in terms of their scale and estimated greenhouse gas reductions.

TABLE 40

Approved methodologies related to woodfuels

Large-scale methodologies directly or indirectly related to woodfuels	Small-scale methodologies directly or indirectly related to woodfuels
AM0007: Analysis of the least-cost fuel option for seasonally operating biomass cogeneration plants – version 1	AMS-I.C: Thermal energy production with or without electricity
AM0036: Fuel switch from fossil fuels to biomass residues in heat generation equipment – version 3	AMS-I.D: Grid-connected renewable electricity generation
AM0042: Grid-connected electricity generation using biomass from newly developed dedicated plantations – version 2	AMS-III.B: Switching fossil fuels
AM0082: Use of charcoal from planted renewable biomass in the iron ore reduction process through the establishment of a new iron ore reduction system – version 1	
ACM000: Consolidated methodology for grid-connected electricity generation from renewable sources – version 11	
ACM0003: Emissions reduction through partial substitution of fossil fuels with alternative fuels or less carbon-intensive fuels in cement manufacture – version 7.3	
ACM0006: Consolidated methodology for electricity generation from biomass residues – version 10	
ACM0018: Consolidated methodology for electricity generation from biomass residues in power-only plants – version 1	

Notes: AM = approved methodology; ACM = approved consolidated methodology; AMS = approved methodology for small-scale projects.

TABLE 41

Examples of CDM projects using woodfuels

Name of CDM project activity	Host party	Project participants (authorized by host party)	Fuel	Scale
Penha renewable energy project	Brazil	Penha Papeise Embalagens Ltd., key associations	Woody biomass	Small
Fuel switch from fossil fuels to biomass briquettes for steam generation at the chemicals manufacturing plant of Lanxess India Pvt. Ltd	India	Lanxess India Pvt Ltd	Biomass	Small
Kim Hock biomass energy and wood recycling plant	Singapore	Kim Hock Corporation Pte Ltd	Woody biomass	Small
Waste heat use at Votorantim Celulose e Papel plant in Jacarei, Brazil	Brazil	Votorantim Celulose e Papel S.A., Ecopart Ltda.	Black liquor	Small
Thermoelectric power plant of 20 MW driven by biomass originating from recently planted energy forest dedicated to the project – Ute Rondon II	Brazil	Eletrogoes S.A	Woody biomass	Large
Empee Distilleries 10 MW woody-biomass-based power project, Tamil Nadu	India	Empee Distilleries Ltd.	Others	Small
Rajang wood-waste biomass project	Malaysia	Bahagaya Sdn Bhd	Woody biomass	Small

Thermoelectric biomass power plant, Rôndonia, Brazil

This project involves the installation of a biomass thermoelectric plant, Rondon II, in the municipality of Pimenta Bueno. The plant is designed to complement energy production at an existing hydroelectric scheme by burning wood harvested from the area to be flooded by the hydroelectric scheme's reservoir and from a recently established bioenergy forest plantation. This will lead to the reduction of CO_2 emissions through the substitution of electricity generated from fossil fuels with renewable energy originating from biomass.

In the absence of project activities the alternatives for disposing of the biomass removed from the reservoir would be wood decay and/or wood burning without treatment or use for energy purposes. In addition, land in the vicinity of the project site would remain in a degraded condition with no social or productive use.

The project is expected to produce approximately 160 000 MWh of electricity per year. The methodology used was AM0042, version 2 (see Table 40).

Empee Distilleries woody biomass power project, India

The proposed project, based in Mukudi village, Pudukottai District, Tamil Nadu, is expected to generate 10 MW of electricity using woody biomass as fuel. The principal species to be used are *Prosopis juliflora*, *Eucalyptus* spp. and *Casuarina* spp.; other types of biomass will be used as auxiliary fuels. Approximately 1 MW of the electricity generated will be used for internal consumption and the balance

Methodology	Annual emission reduction *(tCO$_2$/year)*	Average annual emission reduction *(tCO$_2$/year)*	Total emission reduction by 2012 *(tCO$_2$)*	Total estimated emission reduction by 2020 *(tCO$_2$)*	Total estimated emission reduction by 2030 *(tCO$_2$)*
AMS-I.C	29 526				
AMS-III.B		60	365	365	365
AMS-I.C	26 228				
AMS-III.Q	27 296	17 536	95 536	245 664	3 684 960
AM0042	102 465	102 409	418 575	1 024 653	1 024 653
AMS-I.D	27 567	28 457	135 221	366 213	597 205
AMS-I.C AMS-III.E	26 662	28 310	77 663	307 336	594 889

(9 MW) will be exported to the Tamil Nadu Electricity Board grid, which constitutes part of, and is connected to, India's southern regional electricity grid. The plant will substitute electricity generated by fossil fuels.

The woodfuels to be used in the plan will be purchased from local producers. At present biomass is used as domestic fuel, as animal fodder, for thatching, and as fuel for local thermal-energy-consuming industries such as brick kilns. However, these activities only consume about 30.3 percent of the total biomass generated in Pudukottai District. The remaining 69.7 percent is left on the land to decompose aerobically and is available for other purposes. Domestic users will not be required to change their biomass fuel consumption habits, given that ample supply is available.

Kim Hock biomass energy and wood recycling plant

Kim Hock Corporation is a wood and metal recycling company based in Singapore; the project aims to use wood waste as fuel for a boiler with a capacity of 35 tonnes per hour designed to supply steam and electricity for internal plant use. In addition, wood waste that is surplus to requirements for the boiler will be converted to wood pellets as a renewable fuel source that will be sold on the open market.

The project will reduce emissions by displacing fossil fuel from the conventional oil-fired boiler and fossil-fuel-generated electricity from the local grid system. The project will use biomass boiler technology that will allow the plant to be operated solely on wood waste generated by landscaping and waste-disposal companies. This waste is currently incinerated.

REJECTED PROJECTS

Not all submitted projects are successful in attaining registration and being issued with CERs. Some are rejected at the stage of registration, others later after a review of issuance; examples of the former include two from Brazil and one each from India and Malaysia. These are plants running entirely or partly on biomass, including wood (such as from sawmills, wood waste, woodchips, branches and the tops of trees). The reasons for rejection include (IGES, 2010):

- failure to substantiate the prevailing-practice barrier;
- lack of sustainability of the project activity;
- a flawed investment analysis (e.g. the investment analysis did not reflect the net revenues that would continue to accrue to the project activity beyond the crediting period).

VOLUNTARY CARBON STANDARD

The VCS is a programme within the voluntary carbon market to provide a global standard for voluntary offset projects. It was founded by the Climate Group, the International Emissions Trading Association and the World Business Council for Sustainable Development. VCS offsets must be real (i.e. they must have happened), additional (i.e. be beyond business-as-usual activities), measurable, permanent, independently verified and unique (i.e. not used more than once to offset emissions). All the carbon offsets generated under the programme – “voluntary carbon units” (VCUs) – are registered within the VCS Registry System.

The VCS programme can recognize greenhouse gas offset programmes that meet VCS criteria; programmes approved under the VCS are the CDM, JI and Climate Action Reserve. Such approval can mean recognition of greenhouse gas credits; validator and verifier bodies; and methodology elements. The sectoral scope of the VCS is almost identical to that of the CDM; it contains 15 sectors, including energy industries (renewable/non-renewable sources) within which all wood-based energy projects fall.

About 25 biomass-based projects in the UNFCCC database are in India and Brazil. One of the two Indian examples is a 6 MW power plant that uses wood residues, sawdust and other biomass feedstock; no coal has been used since 2006. Using CDM methodology AM0042 (see Table 40) the project achieved 37 479 tCO_2eq in net emission reductions (24 260 estimated annual VCUs) during the monitoring period. About 32 000 tonnes of wood waste were consumed, which was 33 percent of total fuel consumption (Rithwik Power Projects Limited, 2008).

The remainder of the projects are in Brazil; most are ceramics factories undertaking a fuel-switch in their kilns from either heavy oil or native wood from forests without sustainable forest management to:

- wood from native forests with a sustainable management plan;
- wood from afforestation (e.g. eucalyptus biomass obtained from regulated forest areas) and afforestation wood residues (e.g. woodchips and sawdust);
- wood from reforestation areas (*Eucalyptus* spp. and *Pinus* spp.);
- algaroba wood and eucalypt wood;
- residues from cashew trees (e.g. prunings);
- forestry residues;
- wood residues from construction and industries;
- sawdust (from sawmills);
- non-fossil-fuel-based fraction of industrial waste (e.g. pallets and wooden packages).

The methodology employed for fuel switching from heavy oil to wood in small-scale projects is CDM methodology AMS-I.C (see Table 40). In two such projects the estimated annual VCUs are 42 304 and 27 771. The shift was entirely to wood of different origin (from the above list), involving 100 000 m^3 per year and 75 000 m^3 per year, respectively. Total project emission reductions are 106 877 and 71 812 tCO_2eq, with average monthly emission reductions of 3 562 and 1 995 tCO_2eq, respectively (VCS, 2010; Social Carbon, 2008; Social Carbon, 2009).

For a wood-to-woodfuel switch, CDM methodology AMS-I.E (see Table 40) is employed. Estimated annual VCUs range between 9 000 and 65 000, while the average monthly emission reductions are 600 to 4 000 tCO_2eq (VCS, 2010).

Another project is a co-generation project involving a new biomass boiler (burning only wood residues) and an 8 MW turbine to replace oil-fired boilers and reduce the consumption of grid electricity. The CDM methodology deployed is ACM0006 (see Table 40). The project generates an estimated 76 743 VCUs annually (VCS, 2010). During two monitoring periods (from 1 January 2002 to 31 December 2007 and from 1 January 2008 to 31 October 2008), emission reductions amounted to 388 452 + 85 057 = 473 509 tCO_2eq, with average monthly emission reductions of 5 774 tCO_2eq (EcoSecurities, 2008).

TRANSACTION COSTS (SMALL-SCALE VERSUS LARGE-SCALE APPLICATIONS)

The CDM is likely to entail considerable costs in baseline development, project registration, verification and certification. The "activities implemented jointly" (AIJ) pilot phase and the Prototype Carbon Fund programme give indications of these costs. According to Michaelowa and Jotzo (2005) there is evidence that:

- projects with high implementation costs have high transaction costs as well;
- transaction costs will be higher in countries with an inefficient regulatory framework, putting them at a competitive disadvantage vis-à-vis more efficient countries.

The UNFCCC launched the AIJ pilot phase in 1995 – prior to the proposed implementation of the Kyoto Protocol – in order to learn more about the possible operation of projects under international flexibility mechanisms. The Swedish AIJ programme in the Baltic states is the only AIJ programme that has consistent reported transaction costs in four categories (technical assistance, follow-up, reporting and administration) over time (Michaelowa and Jotzo, 2005).

Michaelowa and Jotzo (2005) analysed the Swedish data in regard to:

- the impacts of project categories – the transaction costs of renewable-energy projects might be expected to be lower than those of energy-efficiency projects because the latter have greater situation-specific planning needs and a higher number of participants;
- the impacts of start date within the same project categories – learning effects should reduce transaction costs of projects that start later;
- economies of scale within the same project categories;
- host-country specifics within the same project categories.

In the Swedish programme, however, no costs for external validation and certification accrued. The average cost of technical assistance and administration was 20.5 percent of total project cost for energy-efficiency projects and only 14.4 percent for renewable-energy projects. There was a declining trend in transaction costs over time, as expected. Economies of scale were important but there were negligible differences in costs between project types of the same size (Michaelowa and Jotzo, 2005).

Certification costs are mainly fixed, as reported by certifiers (e.g. SGS, KPMG, DNV, PricewaterhouseCoopers and EcoSecurities) engaged in validating, monitoring and certifying greenhouse gas abatement projects. SGS, for example, clearly stated that verification and certification costs are relatively independent of project size; it estimated a cost of €17 000 for the first verification and €8 500 for each additional round. KPMG stated that "whereas there will be some correlation between the cost of validation and verification and the size of the project the relationship will not be linear", and DNV suggested that the credibility of certifiers would be jeopardized if their fee was proportional to the quantity of emission reductions verified (Michaelowa and Jotzo, 2005).

For the four Prototype Carbon Fund projects for which there are complete data, there is a close, although not perfect, correlation between the size of project and the transaction costs per tonne of CO_2 reduced. Due to the large size of the projects, the unit cost is much lower than in the Swedish AIJ cases (Michaelowa and Jotzo, 2005).

EcoSecurities examined a 150 MW gas plant with 0.35 million CERs per year and a 2 MW biomass plant generating 35 000 tCERs (temporary CERs) per year. Total transaction costs were €0.3 to €0.7 per tonne for the larger project and €0.4 to €1.1 per tonne for the smaller project. The relatively high costs associated with the larger project were due to the assumption that certification and enforcement costs would be proportional to the quantity of CERs generated (Michaelowa and Jotzo, 2005).

The costs of the operation of the CDM Executive Board are to be borne by project proponents in the form of a fee. This fee is above €0.1 per tonne CO_2eq if a project has an annual reduction of less than 2 000 CERs, assuming a 21-year lifetime. For larger projects, the fee becomes negligible per unit cost of CO_2eq (Michaelowa and Jotzo, 2005).

Empirical evidence suggests, therefore, that economies of scale are the most important factor determining the share of total cost made up by transaction costs because fixed costs form a significant part of transaction costs. Nevertheless, this needs to be confirmed by further research (Michaelowa and Jotzo, 2005).

Evidence from AIJ and emerging CDM projects shows that transaction costs can account for a significant share of the total cost of CDM projects, especially in a market characterized by low permit prices. Transaction costs tend to be higher in project categories with higher implementation costs, and smaller projects are at a disadvantage because fixed costs become a major factor (Michaelowa and Jotzo, 2005).

CDM transaction costs are not easy to define. Chadwick (2006) suggested that they are components in the price of CERs that cannot be attributed to either the physical process of removing greenhouse gases from the atmosphere or the level (or changes in the level) of demand for CERs.

Small-scale renewable-energy and energy-efficiency projects are helping to meet the needs of rural people in developing countries, alleviate poverty and foster sustainable development. However, the low emission reductions per installation are making it difficult for such projects to derive value from participating in the CDM. Negotiators of the Marrakech Accords (November 2001) as well as the CDM Executive Board recognized this problem and adopted simplified CDM modalities and procedures for qualifying small-scale projects. Such projects were defined as renewable-energy project activities with a maximum output capacity equivalent to up to 15 MW; energy-efficiency improvement project activities that reduce energy consumption by an amount equivalent to up to 60 gigawatt hours per year; or other project activities whose emission reductions are less than 60 kilotonnes of CO_2 per year (Purohit, 2009).

The thresholds for the latter two categories were increased by a decision of the 12th Conference of Parties to the UNFCCC in November 2006. Even with the simplified rules, however, the current design of the CDM still means high transaction costs for individual small-scale projects. Costs can be reduced by bundling similar small projects into a single project that is still eligible for the simplified procedures. The 'gold rush' atmosphere of 2005 has also mobilized small-scale project developers (Purohit, 2009).

In a study by Purohit (2009) on biomass gasifier-based projects under the CDM in India, one of the possible barriers to the large-scale dissemination of biomass power was the high upfront cost of these systems. Other barriers included technical barriers, financial drawbacks, a poor institutional framework, short-sighted electric utility policies, and low environmental concern. In the Indian context, wood from natural forests and eucalypt plantations, and agricultural residues, are normally used as fuel and raw material.

The consumption of biomass per unit of electricity generated in the dual-fuel mode of operation of a biomass gasifier-based system depends on factors such as the type of biomass, its moisture content and calorific value, the operating load of the system, and the diesel replacement factor; it is estimated to be in the range of 1.0 to 1.4 kg per kWh at the system's rated capacity. The actual consumption of woodfuel at the 5 to 100 kW biomass gasification projects installed in Gosaba Island, Sundarbans, and West Bengal has been reported to be 0.822 kg per kWh (Purohit, 2009).

MEASUREMENT, REPORTING AND VERIFICATION

The CDM has a registration and issuance approval process; in each country, approval is granted by the designated national authority. Public funding for CDM project activities must not result in the diversion of official development assistance (UNFCCC, 2010).

The VCS has a different system, as described below.

Registration and verification

The VCS Registry System enables the tracking of all VCUs, from issuance to retirement, and is a key part of the VCS programme, ensuring that all VCUs are real, measurable, additional, permanent, independently verified, unique and traceable. Three international companies – APX Inc., Caisse des Dépôts and Markit – are contracted to act as registries that issue, hold, transfer and retire VCUs and interact directly with the VCS project database to upload project documentation and obtain unique serial numbers for each VCU.

The following steps are required to register a project and issue VCUs under the VCS Registry System. First, an accredited validation and verification body must validate the project and verify its greenhouse gas emission reductions or removals. Second, the project is presented to a VCS registry for registration. Third, the VCS registry administrator reviews the project and VCU issuance claim. Fourth, the project is registered and the initial VCUs are issued on the VCS project database. VCUs may also be issued subsequent to the initial issuance of VCUs to the project.

The last step – project maintenance – implies that the project proponent can update project details (VCS, 2010). Microprojects (i.e. <5 000 tCO_2eq savings per year) may be validated and verified by microproject validators and verifiers, who must comply with certain requirements (VCS, 2008).

Methodologies: measurement, monitoring and reporting

VCS methodology elements provide the framework for the development of projects and the quantification of greenhouse gas emission reductions or removals. These elements describe methodologies and methodology revisions, additionality performance tests and tools/modules. The methodology elements of the VCS, the CDM and the Climate Action Reserve are approved under the VCS programme and can be found at www.v-c-s.org.

All methodologies applying for approval under the VCS programme must undergo a double-approval process. They must include applicability criteria that defines the area of project eligibility, a process that determines whether the project is additional or not, determination criteria for the most likely baseline scenario and all necessary monitoring aspects related to monitoring and reporting of accurate and reliable greenhouse gas emission reductions or removals (VCS, 2008).

FINANCE OF CARBON SAVING

Financial information on wood-based projects is not readily available for analysis; often, financial data are not disclosed by companies. The data used in the analysis below (summarized in Table 42) were derived from two main sources: CDM project design documents; and projects funded by the Global Environment Facility (GEF).

CDM wood-based projects

Two examples are described.

- ***Empee Distilleries in India:*** Investment costs, including pre-operational expenses and the total capital investment, were estimated to be US$9.8 million. Average annual operational and maintenance costs, including fuel, administrative

TABLE 42

Emission reductions and costs of various wood-based projects

Project/country	Emission reductions ($MtCO_2eq$)			Costs (*US$ million*)		
	Baseline scenario	Alternative scenario	Incremental reductions	Baseline scenario	Alternative scenario	Incremental cost[a]
CDM (India)	0.37	0.18	0.19	n.a.	13.20	n.a.
CDM (Malaysia)	0.0005	0.1045	0.102[b]	0	7.10	7.10
GEF (Belarus)	n.a.	n.a.	n.a.	5.50	7.51	1.08
GEF (Poland)	n.a.	n.a.	n.a.	0.47	2.60	2.13
GEF (Slovakia)	0.07	0.66	0.59	6.18	8.34	2.16

[a] Difference between the alternative scenario and baseline scenario costs.

[b] Taking leakage into account.

n.a. = Data unavailable.

expenses, salaries and utilities, were estimated to be US$3.4 million. Carbon project development costs were estimated at US$50 000 and monitoring and verification costs at US$10 000 per year. Thus, final costs were an estimated US$13.26 million.

- ***4 MW biomass power plants using waste woodchips and sawdust in Central Java Province, Indonesia*:** The estimated capital investment required to achieve emission reductions of 0.102 Mt of CO_2eq during the seven crediting years (2008–2015) was US$7.1 million.

GEF wood-based projects

GEF projects have the following characteristics, which differ from CDM or VCS projects:

- the objectives normally include the enhancement of energy security through increased energy efficiency and the deployment of renewable energy types;
- projects include institutional capacity building, awareness raising and other similar activities;
- the introduction of new facilities or the upgrading of existing facilities to allow the use of woody biomass would usually be a part of a larger project and would play a demonstration role. The costs associated with this demonstration component are used here for the analysis.

The goal of the project Biomass Energy for Heating and Hot Water Supply (Belarus) was to address the reduction of greenhouse gas emissions in Belarus by increasing the capacity of the government to support biomass energy projects and the capacity of customers to finance and implement them. The baseline scenario was described as “present level of adoption of biomass energy systems continues, with simple, inefficient and unsustainable conversion techniques. Upgrades of boilers at the sites, if they occur at all, are equivalent to gas or oil systems”. The related costs totalled US$5.50 million (US$1.59 million – site owners, in kind; US$1.78 million – site owners, cash; US$2.13 million – government, cash). The project’s technical component involved the conversion of five boilers to enable the use of biomass feedstock in the form of forestry residues and woody waste from woodworking enterprises at a total cost of US$7.51 million (the incremental cost – the difference between the alternative scenario cost and baseline scenario cost – therefore, was US$2.01 million). Direct CO_2eq emission reductions over the 15-year period were estimated to be approximately 1.08 Mt (UNDP, undated).

The objective of the project Integrated Approach to Wood Waste Combustion for Heat Production in Poland was to reduce greenhouse gas emissions by removing barriers to the creation of a viable wood-waste market offering clean energy. Specifically it involved the substitution of 4 MW of heat production capacity using hard coal by 4 000 tonnes of biomass (wood waste) per year, equivalent to about 1 300 tonnes per year of hard coal (less than 10 percent of the identified coal substitution potential of 14 500 tonnes per year). The incremental cost of the project was US$2.136 million.

Under the project Reducing Greenhouse Gas Emissions Through the Use of Biomass Energy in Northwest Slovakia, the baseline scenario – substitution of 44 coal/coke-fired boilers with 22 more efficient coal boilers and 22 natural-gas-fired boilers – produced total emission reductions of 0.068 $MtCO_2eq$ (assuming a project lifetime of ten years) at a cost of US$6.184 million. In the alternative GEF scenario (assuming a project lifetime of ten years) pellet-fired boilers consuming 0.012 Mt of pellets per year would lead to emission reductions of 0.201 $MtCO_2eq$ and a central processing unit that allowed treatment of wood waste with minimal methane emissions would reduce emissions by 0.454 $MtCO_2eq$. The cost of this alternative scenario was estimated at US$8.34 million. Thus, the incremental cost of US2.159 million would produce incremental emission reductions of 0.587 $MtCO_2eq$.

FAO/FO-6998/H.B. GÜNSEN

10. Research, development, demonstration and deployment

This chapter reviews selected issues in research, development, demonstration, deployment and implementation of woodfuel use in climate change mitigation that need to be considered to meet end-user needs.

ESTIMATED BLACK CARBON EMISSIONS FROM TRADITIONAL BIOMASS

There are only a few studies on black carbon (soot) emissions from the household use of biomass for cooking. Based on measurements by Muhlbaier-Dasch (1982) on eleven types of wood, Streets *et al.* (2001) assumed a value of 1 g per kg of black carbon emissions for the combustion of residential biofuels. Bond *et al.* (2004) estimated the black carbon emission factor to be 0.3 to 1.4 g per kg for wood; 1.0 g per kg for crop residues as well as charcoal; 0.5 g per kg for animal dung; and 0.2 g per kg for charcoal-making.

Reddy and Venkataraman (2002) estimated black carbon emissions in India of 0.41 g per kg for wood, 0.47 g per kg for agricultural residues and 0.25 g per kg for dung. In a more recent study, Venkataraman *et al.* (2005) reported measured values of black carbon emissions of 0.48 to 0.55 g per kg for wood, 0.64 g per kg for crop residues and 0.12 g per kg for animal dung. Roden *et al.* (2006) measured emissions from biofuel cooking stoves during a field study in Honduras; average black carbon emissions were 1.5 ± 0.3g per kg.

Cao *et al.* (2007) used measured values of emissions for crop residues in preparing an inventory of black carbon emissions in China; they were 0.52 g per kg for rice and wheat straw; 0.78 g per kg for corn stover; and 0.82 g per kg for cotton stalk. MacCarty *et al.* (2008) reported black carbon and organic matter emissions, and global warming impact, of a charcoal stove and the following four types of wood-fired cooking stoves: three-stone stove; improved stove (Rocket stove); natural draft gasifier stove; and forced-draft gasifier stove. Table 43 shows that black carbon emissions varied widely.

The emission factors of pollutants from stoves depend on various parameters involved in the combustion process, such as the type of fuel, the type and design of the burner, and the operating conditions (Bhattacharya and Salam, 2002). It is almost impossible, therefore, to cite a definitive value. A simplifying assumption is that black carbon emissions per kg of fuel are the same for both traditional and improved stoves and therefore vary according to the fuel used, as follows:

- wood-fired stoves – 1 g per kg;
- crop-residue-fired stoves – 0.75 g per kg;
- dung-fired stoves – 0.25 g per kg.

TABLE 43

Black carbon emission factor for five stoves

Stove type	Emission factor *(g/kg)*
Three-stone	0.88
Rocket stove	1.16
Natural draft gasifier stove	0.28
Forced-draft gasifier stove	0.06
Charcoal stove	0.20

Source: MacCarty *et al.*, 2008.

TABLE 44

Black carbon emissions from biofuel combustion in the residential sector

Energy source	Black carbon emission *(Gg/year)*	Share of global black carbon emissions *(%)*
Wood	880	11.1
Crop residues	393	4.9
Animal waste	208	2.6
Coal	480	6.0
Total	**1 961**	**24.7**

Source: Bond *et al.*, 2004.

In one of the earliest studies of global black carbon emissions, Streets *et al.* (2001) estimated black carbon emissions from the total combustion of all biofuels – wood, crop residues and animal dung combined – using a single emission factor. Bond *et al.* (2004) used separate emission factors for different biofuels used in the residential sector (Table 44). Ventakaraman *et al.* (2005) presented estimates of black carbon emissions from biofuel combustion in India and elsewhere in Asia as well as the 1995 global total using measured values of emissions; the reported global values for wood, crop residues and animal dung were 670 to 820, 230 to 260 and 20 to 50 gigagrams (Gg) per year, respectively.

HOUSEHOLD BIOMASS: CLEAN COOKING DEPLOYMENT STRATEGIES

There is no universal strategy for disseminating clean cooking options. As noted by Barnes *et al.*, (1994), each stove programme "will face a distinctive set of challenges and benefits, depending on local conditions". National strategies for reducing black carbon emissions from residential cooking will need to take into account a wide range of country-specific barriers, constraints and opportunities. The following elements could be considered in the formulation of such strategies.

- The large-scale mitigation of black carbon emissions from residential cooking requires serious government commitment and a national-level programme with policies and targets. The provision of clean cooking options, similar to rural electrification and infrastructure development, needs to be part of the national development agenda. Recent success in Brazil in introducing an improved cooking stove programme appears to be due at least partly to the enthusiasm and commitment of a local politician.

- The large-scale dissemination of improved stoves requires public-sector investment in building capacity, raising awareness and developing technology. Experience in China suggests that government support is also needed for certification systems to standardize stove designs (Sinton *et al.*, 2004).
- Improved cooking stove programmes tend to fail in regions where poor families build their own stoves and collect their fuels free of charge. In such regions, government or donor money could be used to subsidize the cost of improved stoves (Barnes *et al.*, 1994).
- A great deal of effort is often needed to convince users that better options than traditional cooking stoves exist. Thus, a systematic and sustained campaign for creating awareness about the importance of cleaner options is vital. Involving non-governmental organizations and women's groups in these campaigns is also important.
- To be readily accepted, improved stoves must meet the actual needs and preferences of users.
- Improved stoves must be clean and efficient – if the first few users are convinced of the benefits, their positive experiences will draw more users to cleaner options.
- To attract first-time users the stoves must "look" modern. The effectiveness of such an approach to marketing can be seen in the success of new stoves being sold commercially (e.g. the Oorja and Rocket stoves being marketed in India).
- Since many of the potential users earn very low cash incomes (e.g. less than a dollar a day), the initial cost of clean options should be as low as possible; a subsidy may be required.
- The acceptance of improved stoves depends on women's opportunities for paid labour; less time spent on fuelwood collection means more time for income generation. Creating such employment opportunities would thus contribute towards the success of improved-stove programmes.
- Involving private-sector entrepreneurs in building and marketing stoves will ensure a rapid response to user complaints and generate benefits in the form of additional employment.

AN ADVANCED TECHNOLOGY OPTION: WOOD GASIFICATION

Wood can be transformed readily into a synthetic gas (syngas) through a gasification process. Municipalities and the industrial sector are looking for ways to reduce the disposal costs associated with biomass wastes and to produce electricity and other valuable products from them. Biomass gasification has not reached the level of commercial demonstration but shows a great deal of promise.

Gasification is an energy technology that can convert low-value feedstock into high-value products, helping to reduce dependence on foreign oil and natural gas and providing a clean, renewable source of energy. Syngas can be burned directly to produce electricity or further processed to produce liquid fuels, chemicals, substitute natural gas or hydrogen. The basic process and some of the possible products are shown in Figure 3.

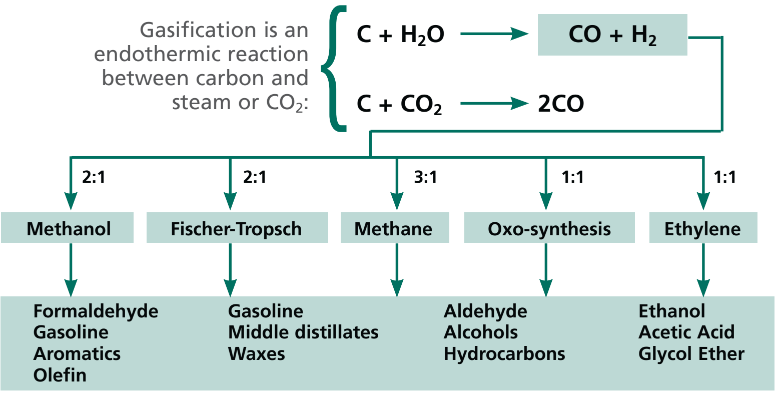
Most gasification processes use biomass feedstock injected with oxygen and steam into a high-temperature, pressurized reactor so that the chemical bonds of the feedstock are broken. The resulting reaction produces syngas – a mixture of hydrogen and carbon monoxide – and small amounts of other gases and impurities such as sulphur, mercury, particulates and trace minerals that are removed by cleaning (carbon dioxide can also be removed at this stage). The cleaned syngas can be used for a wide range of purposes, including the production of substitute natural gas – methane – which can be used in the same way as natural gas. Syngas from wood contains tar (a mixture of hydrocarbon compounds) and other impurities; cleaning tar from syngas is an unresolved problem.

Gasification is the foundation for converting biomass to transportation fuels via one of two basic paths. In one, the syngas undergoes a Fischer-Tropsch reaction to convert it to a liquid product. In the other – the methanol-to-biofuel process – the syngas is converted to methanol, which is then converted to liquid biofuel by reacting it over a bed of catalysts.

The advanced biomass-to-power technology allows the continued use of biomass without the high level of emissions associated with conventional biomass burning. This is because in gasification power plants the pollutants in the syngas are removed before the syngas is combusted. In conventional combustion technologies the pollutants must be captured after the exhaust gas has passed through the boiler or steam generator.

FIGURE 3

Basic process scheme: gasification of biomass



The clean syngas can also be combusted directly (i.e. without conversion to methane) in gas turbines to generate electricity with very low emissions. The gas turbines used in these plants are generally derivatives of the gas turbines in jet engines adapted for use with syngas for power production. These turbines are able to operate on syngas with high levels of hydrogen (typical 50 percent hydrogen by volume). Hot discharge gas from the turbines can be circulated through a heat recovery steam generator, providing additional electricity-generation capacity via a steam turbine (this is called a combined-cycle unit).

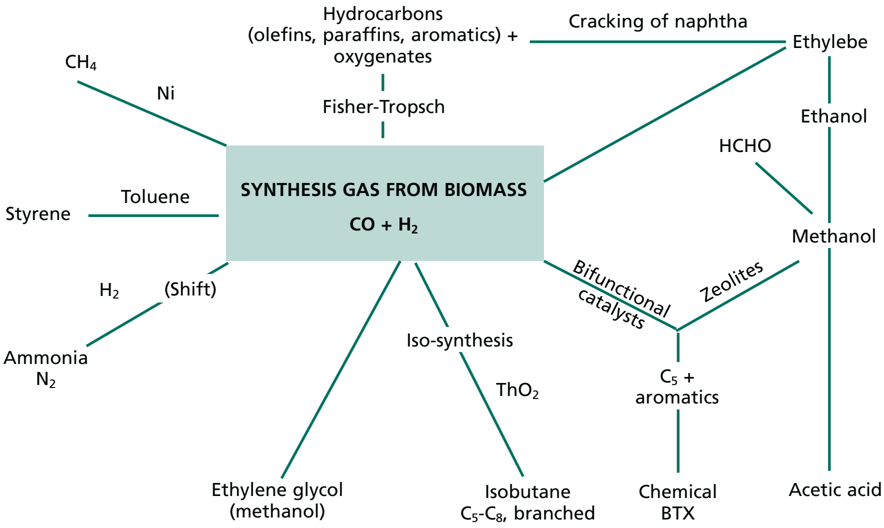
Steam recovered from the gasification process is superheated in the heat recovery steam generator to increase the overall efficiency output of the steam cycle. The full cycle, called the integrated gasification combined cycle, includes a gasification plant, two types of turbine generators (gas and steam), and the heat recovery steam generator. It is a clean and efficient power production system producing nitrogen oxides at levels lower than 0.03 kg per basic emission of coal power generation; combined cycle efficiencies can exceed 65 percent.

It is also possible to use the gas turbine to compress air; this reduces the capital cost of the plant and decreases the amount of power required to supply oxygen in the combustion processes.

Producing more than one product at a time (co-production or "polygeneration") such as the simultaneous production of electricity, steam and chemicals (e.g. methanol and ammonia) is also possible and in some cases improves the plant's financial performance (Figure 4).

FIGURE 4

Main chemicals from synthesis gas



Source: Wender, 1986

Gasification enables the use of biomass to produce electricity with significantly reduced environmental impacts compared to traditional combustion technologies. The reasons for this include the following:

- Syngas is cleaned before combustion – gasification plants therefore produce significantly fewer quantities of noxious air pollutants such as nitrogen oxides and sulphur dioxide.
- Gasification enables the recovery of available energy from low-value materials (e.g. municipal solid waste), thereby reducing the environmental impacts of biodegradation as well as disposal costs.
- The by-products of gasification (e.g. sulphur and ashes) are non-hazardous and are readily marketable.
- Gasification plants use significantly less water than coal combustion plants, and can be designed as zero-liquid water discharge facilities.
- In the last five to ten years, coal gasification for electricity production has reached commercialization, with over 90 installations and 60 manufactures around the world.

The main advantages of gasification are:

- high electrical efficiency;
- the substitution of natural gas or diesel in boilers;
- the distribution of power generation where power demand is low;
- the substitution of gasoline/diesel in internal combustion engines.

The gasification of biomass is not yet commercially viable; to penetrate the market its costs must be lowered considerably. The first successful demonstration of biomass gasification at an industrial scale was at Värnamo in Sweden (the test programme ended in 1999). On the basis of a recent feasibility study, the energy company E. ON Sverige identified 20 potential locations for plants in Sweden.

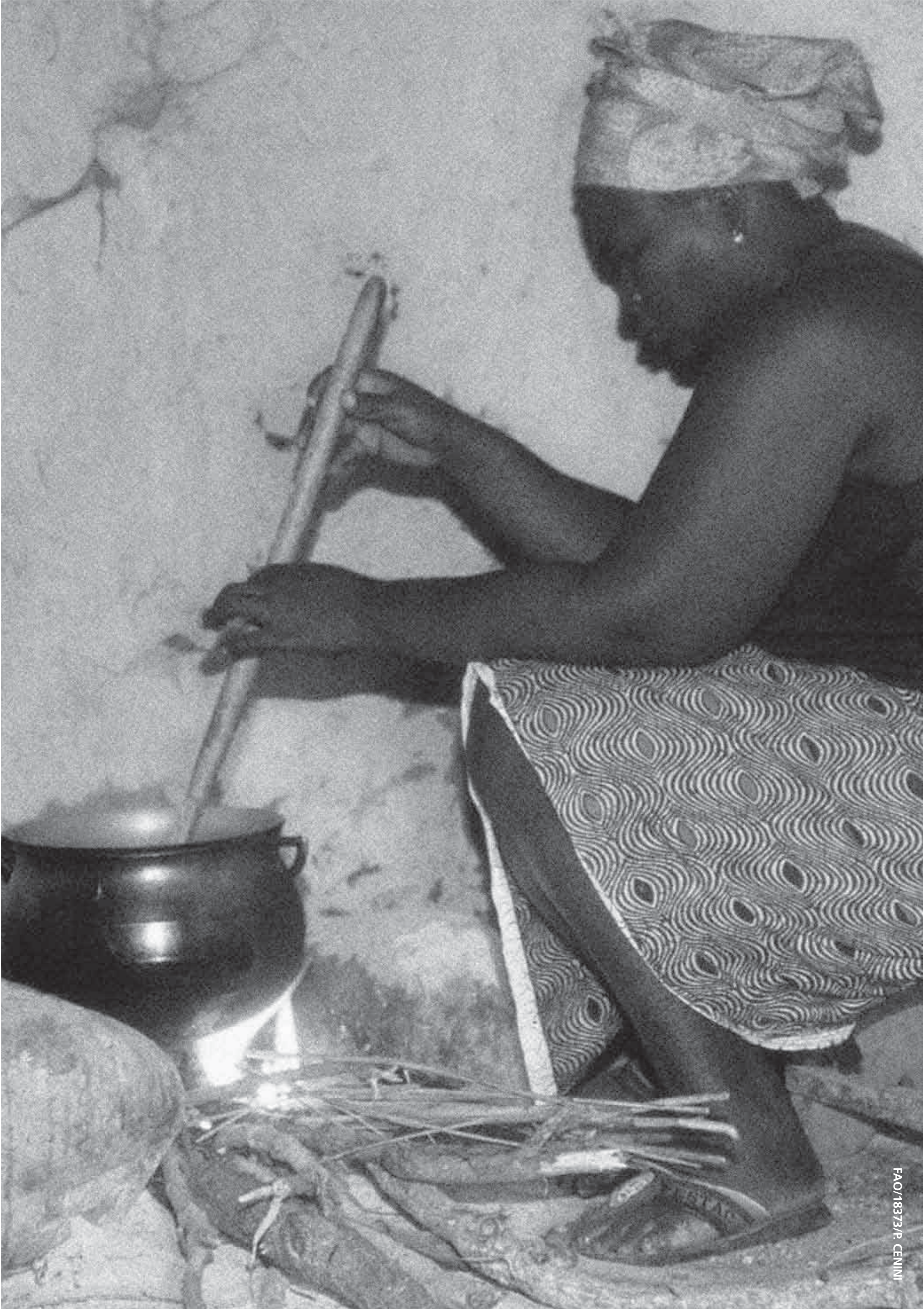
11. Conclusions

Evidence of climate change linked to human-induced increase in greenhouse gas concentrations is well-documented. Due to rapid economic growth and large population size, energy consumption is projected to increase at the highest rates in developing countries. This increase in energy consumption will result in higher greenhouse gas emissions, associated with fossil fuel use. Additional greenhouse gas emissions originate mainly from land-use change, with deforestation in tropical countries.

Long-term and sustainable reductions of CO_2 emissions through land-based activities will to a large extent have to come from the use of wood for bioenergy and products. The provisions of the Kyoto Protocol with respect to sinks can be seen as a valuable incentive to protect and enhance carbon stocks now, while at the same time providing the biomass resources needed for the continued substitution of fossil fuels in the future.

Wood energy offers significant, cost-effective and perpetual opportunities for greenhouse gas emission reductions. Additional benefits offered are employment creation in rural areas, energy security, better waste control, and potentially benign effects with regard to biodiversity, desertification and recreational value. Wood energy can therefore significantly contribute to sustainable development both in developed and less developed countries, provided that all issues related to its practical exploitation are carefully considered.

There are nevertheless some barriers to woodfuel substitution including the up-front investment costs. There are three key issues that must be first addressed when considering woodfuel substitution. First, greater efforts are needed to address the efficiency and impacts of the traditional biomass sector, since it will continue to play an important role, especially in Africa and South Asia. Second, the actual emission savings associated with improvements in traditional biomass use are highly uncertain; research should address the need for better data and also the impacts of black carbon (soot), a short-lived pollutant that contributes to climate forcing. Third, advanced technologies that use wood more efficiently, especially gasification methods, require further demonstration at the commercial scale. Fourth, complications in implementing woodfuel programmes and projects – in both the traditional and modern bioenergy sectors – require more coordinated testing and evaluation. Fifth and finally, policies and institutions are needed that can incentivise and facilitate comprehensive management of forests for multiple uses, including carbon sequestration, fuel, shelter, recreation and industrial products.



FAO/18373/P. CENINI

Bibliography

ABARE. 2009. *Energy in Australia in 2009.* Canberra, Australian Bureau of Agricultural and Resource Economics (also available at www.abare.gov.au/interactive/09).

Abdallah, J.M. & Monela, G.G. 2007. Overview of miombo woodlands in Tanzania (available at www.metla.fi/julkaisut/workingpapers/2007/mwp050-02.pdf).

ADAS. 2006. *Potential impacts of future energy policy on UK biodiversity*. SD0307. Report for Department of Environment, Food and Rural Affairs. London, ADAS.

Bailis, R., Ezzati, M. & Kammen, D. 2005. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. *Science*, 308(5718): 98–103.

Barnes, D.F., Openshaw, K. Smith, K. & van der Plas, R. 1994. *What makes people cook with improved biomass stoves? A comparative international review of stove programs.* Technical Paper Number 242. Energy Series. Washington, DC, World Bank.

Bhattacharya, S. 2009. Burn epidemiology: an Indian perspective. *Indian Journal of Plastic Surgery*, 42(2): 193–194.

Bhattacharya, S. C. & Jana, C. 2009. Renewable energy in India: Historical developments and prospects. *Energy Policy*, 34(8): 981–991.

Bhattacharya, S. C. & Salam, P. A. 2002. Low greenhouse gas biomass options for cooking in the developing countries. *Biomass and Bioenergy*, 22(4): 305–317.

Biran, A., Abbot, J. & Mace, R. 2004. Families and firewood: a comparative analysis of the costs and benefits of children in firewood collection and use in two rural communities in sub-Saharan Africa. *Human Ecology*, 32: 1–25.

Bond, T.C., Streets, D. G. Yarber, K.F., Nelson, S.M., Woo, J.-H. & Klimont, Z. 2004. A technology-based global inventory of black and organic carbon emissions from combustion. *Journal of Geophysical Research*, 109.

Bond, T. C. & Sun, H. 2005. Can reducing black carbon emissions counteract global warming? *Environmental Science and Technology*, 39(16): 5921–5926.

Bradley, D. 2009. Canada report on bioenergy 2009. *Climate Change Solutions*, 7 July.

Bruce N.G., Perez-Padilla R. & Albalak, R. 2002. *The health effects of indoor air pollution exposure in developing countries.* Geneva, Switzerland, World Health Organization.

Cao, J.J., Lee, S.C., Chow, J.C., Watson, J.G., Ho, K.F., Zhang, R.J., Jin, Z.D., Shen, Z.X., Chen, G.C., Kang, Y.M., Zou, S.C., Zhang, L.Z., Qi, S.H., Dai, M.H., Cheng, Y., Hu, K. 2007. Spatial and seasonal distributions of carbonaceous aerosols over China. *Journal of Geophysical Research*,112, D22S11. doi:10.1029/2006JD008205.

Carle, J. & Holmgren, P. 2008. Wood from planted forests: a global outlook 2005–2030. *Forest Products Journal*, 58(12): 6–18.

CCBA. 2005. *The Climate, Community and Biodiversity Alliance project design standards.* Washington, DC, Climate Community and Biodiversity Alliance.

Chadwick, B. P. 2006. Transaction costs and the Clean Development Mechanism. *Natural Resources Forum*, 30: 256–271.

DEFRA. 2002. *Growing short rotation coppice – best practice guidelines for applicants to DEFRA'S energy crops scheme*. London, Department of Environment, Food and Rural Affairs.

ECCM. 2006. *Environmental standards for biofuels.* London, Edinburgh Centre for Carbon Management (also available at www.lowcvp.org.uk/assets/reports/Final percent20LCVP percent20Environmental percent20Standards percent20Report.doc).

EcoSecurities. 2008. Nobrecel biomass to energy project. VER monitoring report. Monitoring periods 01/01/2002–31/12/2007 and 01/01/2008 – 31/10/2008.

EPE. 2009. *Balanço energético nacional 2009: ano base 2008 resultados preliminares.* Rio de Janeiro, Brazil, Empresa de Pesquisa Energética.

ESMAP. 2010. *Sustainable production of commercial wood fuel: lessons and guidance from two strategies.* World Bank Energy Sector Management Assistance Program. Washington, DC, World Bank.

European Commission. 2006. *Biomass action plan*. Brussels, European Commission.

European Commission. 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

European Pellet Centre. 2009. Final report on producers, traders and consumers of wood pellets (available at www.pelletsatlas.info).

European Pellet Centre. 2010. European Pellet Centre (available at www.pelletcentre.info).

Ezzati, M. & Kammen, D.M. 2001. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *Lancet* (British edition), 358(9282): 619–624.

Ezzati, M. & Kammen, D.M. 2002. Evaluating the health benefits of transitions in household energy technologies in Kenya. *Energy Policy*, 30(10): 815–826.

Faaij, A.P.C. 2006. Bioenergy in EU: changing technology choice, *Energy Policy*, 34: 322–342.

FAO. 2004. *Unified Bioenergy Terminology*. Rome.

FAO. 2005. *Global forest resources assessment 2005: South Africa country report*. Rome (available at ftp://ftp.fao.org/docrep/fao/010/ai961E/ai961E00.pdf).

FAO. 2006a. *Global Forest Resources Assessment 2005 – progress towards sustainable forest management.* FAO Forestry Paper 147. Rome (also available at ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E00.pdf).

FAO. 2006b. *Global planted forests thematic study: results and analysis*. Planted Forests and Trees Working Paper FP38E. Rome (available at www.fao.org/docrep/012/j9429e/j9429e00.pdf).

FAO. 2008. *Responsible management of planted forests: voluntary guidelines.* Working Paper FP/37/E. FAO, Rome (available at www.fao.org/docrep/009/j9256e/J9256E00.htm).

FAO. 2009. *Planted forests and second-generation biofuels*. Planted Forests and Trees Working Paper FP/42E. Rome.

FAO. 2010a. FAOSTAT (available at http://faostat.fao.org).

FAO. 2010b. Woodfuels and climate mitigation: case studies in Brazil, India and Mexico. Forests and Climate Change Working Paper 6. Rome.

FAO. 2010c. *Global Forest Resources Assessment 2010: Key findings.* Rome. (available at www.fao.org/forestry/fra/fra2010).

Fernandes, S.D., Trautmann, N.M., Streets, D.G., Roden, C.A. & Bond, T.C. 2007. Global biofuel use, 1850–2000. *Global Biogeochemical Cycles*, 21.

Forest Stewardship Council. 1996. *FSC international standard. Principles and criteria for forest stewardship.* FSC-STD-01-001 (version 4-0). Bonn.

Forest Stewardship Council. 2006a. *FSC accredited forest stewardship standards.* FSC Accreditation Business Unit. Bonn.

Forest Stewardship Council. 2006b. *Regional guidelines and standards*. Bonn (also available at www.rainforest-alliance.org. programs/forestry/smartwood/certification/regional).

Forest Stewardship Council. 2010. *Global FSC certificates: type and distribution.* February 2010. Bonn.

Hansson, J. & Berndes, G. 2009. Future bioenergy trade in the EU: modelling trading options from a cost-effectiveness perspective. *Journal of Cleaner Production* 17: S27–S36.

Hansson, J., Berndes, G., Johnsson, F. & Kjarstad, J. 2009. Co-firing biomass with coal for electricity generation – an assessment of the potential in EU27. *Energy Policy* 37: 1444–1455.

Heinimö, J., Pakarinen, V., Ojanen, V. & Kässi, T. 2007. International bioenergy trade – scenario study on international biomass market in 2020. Report for the International Energy Agency. Lappeenranta, Finland, Lappeenranta University of Technology.

Hillring, B. 2006. World trade in forest products and woodfuel. *Biomass and Bioenergy* 30(10): 815–825 (also available at www.iso.org/iso/en/ISOOnline.frontpage).

IBGE. 2009. Instituto Brasileiro de Geografia e Estatística. Produção da extração vegetal e silvicultura 2008. Rio de Janeiro: IBGE, Coordenação de Agropecuária, v. 23. 47 p.

IEA. 2002. *World energy outlook 2002.* Paris, International Energy Agency.

IEA. 2006. Energy for cooking in developing countries. *World energy outlook 2006.* Paris, International Energy Agency.

IEA. 2008. *Principles of nutrient management for sustainable forest bioenergy production.* Biomass Production for Energy from Sustainable Forestry Technology Progress Report, IEA Bioenergy Task 31, ExCo62 Doc 07.03b, October (also available at www.ieabioenergytask31.org).

IEA. 2009a. *Bioenergy – a sustainable and reliable energy source: a review of status and prospects.* Paris, International Energy Agency.

IEA. 2009b. *World energy outlook 2009.* Paris, International Energy Agency.

IEA. 2010a. Statistics and balances (available at www.iea.org/stats/index.asp).

IEA. 2010b. *Opportunities and barriers for international bioenergy trade.* IEA Bioenergy Task 40 report, May 2010. Paris.

IEA Bioenergy Task 40. 2009. *World maritime biofuel shipping study.* Paris, International Energy Agency.

IGES. 2010. *IGES CDM review and rejected project database.* Hayama, Japan, Institute for Global Environmental Studies.

IPCC, 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave & L.A. Meyer. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

ISO. 2006. ISO 14040: Environmental management – life cycle assessment – principles and framework (available at www.iso.org/iso/catalogue_detail?csnumber=37456).

Johnson, F., Rosillo-Calle, F. 2007. Biomass, livelihoods and international trade: Challenges and Opportunities for the EU and Southern Africa. Stockholm Environment Institute.

Johnson, T., Alatorre, C. Romo, Z. & Liu, F. 2009. *Low carbon development for Mexico*. Conference edition. Washington, World Bank.

Junginger, M. 2006. *Overview of biomass – related sustainability certification efforts and policy in IEA Bioenergy*. IEA Bioenergy Task 40. Paris, International Energy Agency.

Junginger, M., Sikkema, R. & Faaij, A. 2009. Analysis of the global pellet market including major driving forces and possible technical and non-technical barriers. EIE/06/020/SI2.448557. (available at www.pelletsatlas.info).

Leach, G. & Johnson, F. 1999. *Modern bioenergy – a primer.* Stockholm, Stockholm Environment Institute.

Leach, G. & Mearns, R. 1988. *Beyond the woodfuel crisis: people, land, and trees in Africa.* London, Earthscan.

MacCarty, N., Ogle, D., Still, D., Bond, T. & Roden, C. 2008. A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. *Energy for Sustainable Development* XII(2).

Malimbwi, R.E., Zahabu, E. & Mchome, B. 2007. *Situation analysis of charcoal sector in Dar es Salaam, charcoal supply and consumption*. Morogoro, Tanzania, Sokoine University of Agriculture.

McKinsey & Company. 2009. *Pathways to a low-carbon economy – Version 2 of the global greenhouse gas abatement cost curve*.

McPeak, J. 2002. Fuelwood gathering and use in northern Kenya**.** Paper prepared for presentation to the meeting of the Association for Politics and Life Sciences, 11–14 August, Montreal, Quebec.

Mead, D.J. 2005. Forests for energy and the role of planted trees. *Critical Reviews in Plant Sciences*, 24(5): 407–421.

Michaelowa, A. & Jotzo, F. 2005. Transaction costs, institutional rigidities and the size of the Clean Development Mechanism. *Energy Policy*, 33: 511–523.

Muhlbaier-Dasch, J. 1982. Particulate and gaseous emissions from wood-burning fireplaces. *Environmental Science and Technology*, 16: 639–645.

NationMaster. 2010. UN statistics, as displayed graphically on: www.nationmaster.com.

Pekska-Blanchard, M., Dolzan, P., Grassi, A., Heinimo, J., Junginger, M., Ranta, T. & Walter, A. 2007. *Global wood pellets markets and industry: policy drivers, market status and raw material potential*. IEA Task 40 (available at www.bioenergytrade.org).

Practical Action Consulting. 2009. *Small-scale bioenergy initiatives: brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa*. Prepared for PISCES and FAO by Practical Action Consulting, January 2009.

PricewaterhouseCoopers. 2006. *Development of environmental and social reporting guidance on the provenance of biofuels supplied through the renewable transport fuels obligation. A proposal for the low carbon vehicle partnership*. London, UK.

Purohit, P. 2009. Economic potential of biomass gasification projects under clean development mechanism in India. *Journal of Cleaner Production*, 17: 181–193.

Rainforest Alliance. 2007. *Rainforest Alliance/SmartWood generic standards for assessing forest management.* SmartWood Program FM-12. New York, United States, Rainforest Alliance. 24 pp. (also available at www.rainforest-alliance.org/forestry/documents/generic_standards.pdf).

Raison, R. 2002. Environmental sustainability of forest energy production. *In* J. Richardson, R. Björheden, P. Hakkila, A.T. Lowe & C.T. Smith, eds. *Bioenergy from sustainable forestry: guiding principles and practice.* Netherlands, Kluwer Academic Publishers.

RCEP. 2004. *Biomass as a renewable energy source.* London, Royal Commission on Environmental Pollution (available at www.rcep.org.uk/biomass/Biomass percent20Report.pdf).

Reddy, M.S. & Venkataraman, C. 2002. Inventory of aerosol and sulphur dioxide emissions from India: I – Fossil fuel combustion. *Atmospheric Environment*, 36(4): 677–697.

Rithwik Power Projects Limited. 2008. VCS standard. VER monitoring report – Version I. Monitoring period 31/10/2006-24/03/2008.

Roden, C. A., Bond, T. C., Conway, S., Benjamin, A. & Pinel, O. 2006. Emission factors and real-time optical properties of particles emitted from traditional wood burning cookstoves. *Environmental Science and Technology*, 40: 6750–6757.

Rodriguez, D. 2006. The first Hewsaw to Argentina. *Hewsaw Team,* 1: 4.

Sanchez, T. 2010. *The hidden energy crisis: how policies are failing the world's poor.* Rugby, UK, Practical Action Publishing.

Santana, R.C., Barros, N.F. & Comerford, N.B. 2000. Above-ground biomass, nutrient content, and nutrient use efficiency of eucalypt plantations growing in different sites in Brazil. *New Zealand Journal of Forestry Science*, 30: 225–236.

Schubert, R., Schellnhuber, H.J., Buchmann, N., Epiney, A., Griesshammer, R., Kulessa, M., Messner, D., Rahmstorf, S. & Schmid, J. 2009. *Future bioenergy and sustainable land use*. German Advisory Council on Global change (WBGU). London, Earthscan.

Scottish Natural Heritage. 2007. *Biomass energy and the natural heritage*. Consultation Information. Inverness, UK, Scottish Natural Heritage.

Sinton, J. E., Smith, K., Peabody, J., Yaping, L., Xiliang, Z., Edwards, R., Quan, G. 2004. An Assessment of Programmes to Promote Improved Household Stoves in China, *Energy for Sustainable Development*, 8(3):33–52.

Smeets, E. & Faaij, A. 2007. Bioenergy potentials from forestry in 2050: an assessment of the drivers that determine the potentials. *Climatic Change*, 81: 353–390.

Smith, K.R., Samet, J.M., Romieu, I. & Bruce, N. 2000a. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax*, 55: 518–532.

Smith, K.R., Uma, R., Kishore, V.V.N., Zhang, J., Joshi, V. & Khalil, M.A.K. 2000b. Greenhouse implications of household stoves: an analysis for India. *Annual Review of Energy and the Environment*, 25: 741–763.

Social Carbon. 2008. Guaraí, Itabira and Santa Izabel Ceramics fuel switching project. Monitoring report, version 03. Monitoring period 01/04/2006–30/09/2008.

Social Carbon. 2009. Arrozal, GGP and Sul América Ceramics fuel switching project. Monitoring report, version 06. Monitoring period 2009 01/04/2006–31/03/2009.

Stern, N. 2007. Stern Review on the Economics of Climate Change: Part III: The Economics of Stabilisation. HM Treasury, London: hm-treasury.gov.uk/sternreview_index.htm

Streets, D., Gupta, S., Waldhoff, S.,Wang, M., Bond, T. & Yiyun, B. 2001. Black carbon emissions in China. *Atmospheric Environment*, 35: 4281–4296.

Tanzania Ports Authority. 2007. Tanzania Ports Authority website (available at www.tanzaniaports.com/dsm/index.htm).

TATEDO. 2005. Potential for small-scale biomass power plant in Tanzania. Tanzania Traditional Energy Development and Environment Organisation, Dar es Salaam.

UNCHS. 1993. *Application of biomass-energy technologies*. Nairobi, United Nations Centre for Human Settlements (Habitat).

UNFCCC. 2010. Flexible mechanisms (Clean Development Mechanism, emissions trading, joint implementation) (available at www.unfccc.int; cdm.unfccc.int/index.html).

UNDP. Undated. United Nations Development Programme Global Environment Facility project document: biomass energy for heating and hot water supply in Belarus (available at un.by/pdf/Belarus%20CC%20Biomass%20ProDoc.pdf).

VCS. 2008. Voluntary carbon standard 2007 (available at www.v-c-s.org).

VCS. 2010. VCS program normative document: project registration and VCU issuance process, v1.2. (available at http://www.v-c-s.org/).

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A.H. & Friedlander, S.K. 2005. Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. *Science*, 307(5714): 1454–1456.

Walter, A., Dolzan, P. & Piacente, E. 2006. Biomass energy and bio-energy trade: historic developments in Brazil and current opportunities. Country report: Brazil – Task 40 – sustainable bioenergy trade; securing supply and demand. Final version (available at www.bioenergytrade.org/downloads/brazilcountryreport.pdf).

Wender, I. 1986. Synthesis gas as a source of fuels and chemicals: C-1 chemistry *Annual Review of Energy*, 11: 295–314.

Wiskerke, W. 2008. *Towards a sustainable biomass energy supply for rural households in semi-arid Shinyanga, Tanzania: a cost/benefit analysis*. Utrecht, the Netherlands, Department of Science, Technology and Society, Utrecht University.

Wiskerke, W.T., Dornburg, V., Rubanza, C.D.K., Malimbwi, R.E. & Faaij, A.P.C. 2010. Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania. *Renewable and Sustainable Energy Reviews*, 14: 148–165.

Woods, J., Tipper, R., Brown, G., Diaz-Chavez, R., Lovell, J. & de Groot, P. 2006. *Evaluating the sustainability of co-firing in the UK.* Report for the UK Department of Trade and Investment.

World Resources Institute. 2008. EarthTrends database (available at www.wri.org).

WorldWatch Institute. 2007. *Biofuels for transport: global potential and implications for sustainable energy and agriculture.* London, Earthscan.

World Wide Fund for Nature. 2006. WWF and the EU Biofuels Communication. Belgium: World Wide Fund for Nature Agriculture European Policy Office.

162
FAO FORESTRY PAPER

What woodfuels can do to mitigate climate change

Climate change can be mitigated in several ways, but most strategies emphasize reducing greenhouse gas emissions by reducing energy use and switching to energy sources that are less carbon intensive than fossil fuels. This publication explores the scope, potential and implications for using woodfuels to replace fossil fuels and thereby contribute to climate change mitigation. It analyses the current woodfuel offset mechanisms in place and their relative emission reduction potentials. The scope is limited to solid woodfuels (fuelwood, charcoal, prepared biomass such as woodchips and pellets, and recovered products or residues from wood processing industries). However, some themes covered will be applicable to all woodfuels, notably the socio-economic and environmental impacts, financing options and overall development implications of more intensive and efficient use of woodfuels. The publication will be of interest to specialists and policy-makers in forestry, climate change and renewable energy, as well as to forest managers, students and general audiences interested in learning more about the role of forests in energy production and the resulting mitigation potential.

ISBN 978-92-5-106653-9 ISSN 0258-6150

9 789251 066539
I1756E/1/09.10