Forests and Climate Change Working Paper 6

Woodfuels and climate change mitigation

Case studies from Brazil, India and Mexico

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Food and Agriculture Organization of the United Nations

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Foreword

Bioenergy is a here-and-now option that could allow us to decarbonise the global economy before massive investments lock us into a trend of rising emissions. Bioenergy has the potential to shift the geography of international energy markets and challenge the petroleum economy. The world is firmly engaged on a trajectory of increased greenhouse gas (GHG) emissions that, if left unaltered, will trigger massive disruptions to the global climate system. This is confirmed in the 'Reference Scenario' depicted in the International Energy Agency's (IEA) World Energy Outlook 2007. The IEA predicts that global energy demand will increase by 55 per cent in the next quarter of a century, with coal use rising most in absolute terms, followed by the other major fossil fuels. This pattern in demand, according to the IEA, will lead to global GHG emissions climbing to 57 per cent above 2005 levels in 2030. This figure is in line with the worst case scenarios presented in the IPCC Fourth Assessment report on climate change which says that CO_2 emissions would have to fall 50 per cent from current levels by 2030 if we are to stabilize CO_2 concentrations in the atmosphere and avoid long-term effects of climate change. Over the next 20 to 25 years, the IEA estimates there will be global investment of US$20 trillion on oil and gas exploration, the construction of power stations and other energy infrastructure, mostly in emerging economies. By comparison, a small amount will be dedicated to renewables and bioenergy. If we consider that most energy assets are built to last for between three to five decades, the choices we are making now will decide the future for the world's energy profile and the environment.

In the coming 10 to 15 years, the carbon intensity of our economies must be lowered by deploying highly efficient technologies and alternatives to fossil fuels. Every effort must be made to get the most out of currently available technologies and to invest in those that can promise results in the near term. Wood energy fits the bill perfectly, making it a real and practical solution to "*decarbonize*" the global economy. Sustainably managed planted and natural forests, including those managed for wood fuel, can help avoid or reverse deforestation and can offset carbon emissions by serving as carbon "sinks". While burning fossil fuels releases CO_2 that has been locked up for millions of years, burning biomass simply returns to the atmosphere the CO_2 that was absorbed as the plants grew. Under sustainable management, this CO_2 is again recaptured by the growing forest, and there is no net release of CO_2.

If wood fuel is substituted for fossil fuels, land used for sustainable biomass and bioenergy production can continue to provide emissions reductions indefinitely. Often there are opportunities for synergy between wood energy and timber production and management of forests as carbon sinks, particularly on a regional scale.

This publication examines the scope and potential for wood fuels to replace fossil fuels thereby contributing to climate change mitigation in three countries – Brazil, India and Mexico. The potential for and implications of wood fuel development for climate change mitigation is analyzed. The publication also presents the current (woodfuel) offset mechanisms in place and their relative emissions reduction potentials.

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Acronyms

ADEC	Asia-Pacific Economic Cooperation Council
CFC	clorofluorocarbon
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CDM	Clean Development Mechanism
CONAFOR	Mexican National Forestry Commission
DM	dry matter
FSI	Forest Survey of India
GDP	gross domestic product
GHG	greenhouse gas
GIS	Geographic Information System
HFC	hydrofluorocarbon
IEA	International Energy Agency
INEE	Brazilian Institute of Energy Efficiency
INEGI	Mexican National Institute of Statistics, Geography and Informatics
IPCC	International Panel on Climate Change
LPG	liquefied petroleum gas (propane/butane)
LULUCF	land use, land-use change and forestry
MAI	mean annual increment
N_2O	nitrous oxide
NCAER	Indian National Council of Applied Economic Research
NFY	Mexican National Forest Yearbook
NGO	non-governmental organization
NO_2	nitrogen oxide
NMVOC	non-methane volatile organic compound
NSSO	Indian National Sample Survey Organization
OLADE	Latin American Energy Organization
PECC	Mexican Special Climate Change Programme
PFC	perfluorocarbon
PNE	Brazilian National Energy Plan
PPCDAM	Brazilian Action Plan for the Prevention and Control of Deforestation in the Legal Amazon Region
PROFEPA	Mexican Federal Environmental Protection Agency
REDD	Reducing Emissions from Deforestation and Forest Degradation
SF_6	sulphur hexafluoride
Sida	Swedish International Development Cooperation Agency
TERI	The Energy Research Institute
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

Metric prefixes

giga	10^9
mega	10^6
peta	10^{15}
tera	10^{12}

1. Introduction

Bioenergy is a here-and-now option that could allow the world to "decarbonize" the global economy before massive investments lock it into a trend of rising emissions. Bioenergy has the potential to shift the geography of international energy markets and challenge the petroleum economy. The world is firmly engaged on a trajectory of increased greenhouse gas (GHG) emissions that, if left unaltered, will trigger massive disruptions in the global climate system. This is confirmed in the "reference scenario" depicted in the International Energy Agency's (IEA) World Energy Outlook 2007. This predicts that global energy demand will increase by 55 percent in the next quarter of a century, with coal use rising most in absolute terms, followed by the other major fossil fuels. According to IEA, this pattern in demand will lead to global GHG emissions in 2030 that are 57 percent above their 2005 levels. This figure is in line with the worst-case scenarios presented in the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report on climate change, which says that carbon dioxide (CO_2) emissions would have to fall by 50 percent of current levels by 2030 to protect humanity from the effects of global warming. Over the next 20 to 25 years, IEA estimates that global investments of US$20 trillion will be made in oil and gas exploration and in the construction of power stations and other energy infrastructure, mostly in emerging economies. Investments in renewable fuels and bioenergy will be far smaller. Given that most energy assets are built to last for between three to five decades, the choices made now will decide the future for the world's energy profile and the environment.

The role of woodfuels

In the coming ten to 15 years, the carbon intensity of world economies must be lowered by deploying highly efficient technologies and alternatives to fossil fuels. Every effort must be made to get the most out of currently available technologies and to invest in those that promise results in the short term. Wood energy is a real and practical option for decarbonizing the global economy. Sustainably managed planted and natural forests, including ones managed for woodfuel, can help avoid or reverse deforestation and can offset carbon emissions by serving as carbon sinks. While burning fossil fuels releases CO_2 that has been locked up for millions of years, burning biomass simply returns to the atmosphere the CO_2 that was absorbed as the plants grew. Under sustainable management, this CO_2 is recaptured by the growing forest, and there is no net release of CO_2.

If woodfuel substitutes fossil fuels, the land used for sustainable biomass and bioenergy production can continue to provide emission reductions indefinitely. There are often opportunities for synergy between the production of wood energy and timber and the management of forests as carbon sinks, particularly on the regional scale.

This document analyses current and potential woodfuel utilization and its contribution to climate change in Brazil, Mexico and India. Current woodfuel consumption and supply are examined in terms of end-use sectors and sources. Potential production is assessed, and the role of forests and woodfuels in GHG emissions is analysed, as are the mitigation policies adopted in this sector. Current mitigation policies for forestry and a set of feasible interventions for reducing emissions – including the substitution of fossil fuels with woodfuels – are evaluated in detail, along with their impacts on forests, wood prices, forest industries, investment and employment. Recommendations are made on the policy actions needed for the successful substitution of fossil fuels with woodfuels.

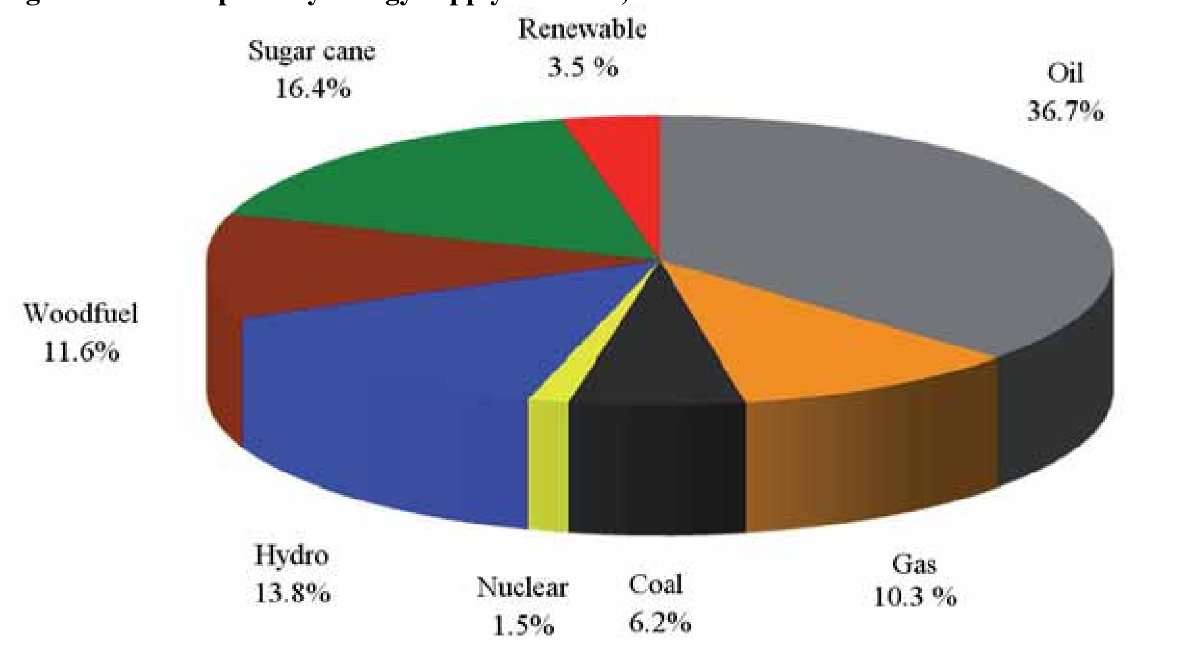
2. Woodfuel development and climate change mitigation in Brazil

Alexandre Uhlig

Introduction

Wood has always played a key role in Brazilian industries and households, and represents about 11.6 percent of the country's total primary energy supply (Figure 2.1). It is easy to understand this importance, considering the magnitude of the country's wood resource. Brazil's native forests cover about 478 million hectares, accounting for 12.1 percent of the world's total woodlands (FAO, 2009), while the afforested area is about 4.5 million hectares, the ninth largest in the world (ABRAF, 2006). Forestry contributes about US$28.2 billion – or 2.8 percent – of Brazilian gross domestic product (GDP) (FAO, 2009). However, even with favourable climatic conditions, large availability of agricultural land and good forestry technology, wood is becoming a scarce resource.

Figure 2.1: Total primary energy supply in Brazil, 2008



Source: EPE, 2009.

Signals of difficulties in supplying Brazil's wood demand can be observed in the reduction of wood production and exports, the escalation of prices, and the government's recognition of the urgent need to promote reforestation. The native forests are fast losing importance in this context. In 1990, roundwood production from Brazilian forests was 144.5 million cubic metres, with 32.5 percent coming from planted forests; in 2007 production had declined to 121.5 million cubic metres, with 86.5 percent from planted forests (IBGE, 2009b). In other words, over the last 17 years, total roundwood production has been decreasing by 1.0 percent per year, and that from natural forests by 10.0 percent per year. Even with their annual growth rate of 4.8 percent, planted forests cannot cope with the wood demand for the coming years, taking into account industrial and energy needs (IBGE, 2009b).

If national wood supply and demand become unbalanced, environmental concerns and doubts about the sustainability of intensive biofuel use will grow. Although most deforestation in Brazil is caused by land clearing for agriculture and cattle raising, woodfuel production for industrial use is also contributing to the worrying rates of deforestation. Examples of situations where reducing the depletion of natural forest resources requires urgent attention include the pressure on savannah cover (*caatinga*) in Northeast Region, to supply fuelwood for gypsum kilns, or charcoal production for the pig iron industry in the border of Amazonian Forest; both of these regions face growing difficulty in maintaining a regular supply of fuel. Commercial fuelwood sales from both native forests and forestry plantations in Brazil amounted to 84 million cubic metres in 2008, and generated US$1.03 billion[1] in annual sales (IBGE, 2009b).

In spite of wood's importance and the country's potential for decreasing GHG emissions, Brazil does not give due attention to this source of energy and is not encouraging forest planting for energy use. However, the Brazilian government has recently created a public body that is expected to manage the sustainable growth of woodfuel use for energy purposes, thus contributing to not only maintenance of the energy matrix with low carbon emissions, but also carbon sinks.

Current energy and woodfuel supply and demand

In Brazil, energy consumption has increased by 35.8 percent over the last ten years, and per capita energy use by 17.7 percent (EPE, 2008). Total primary energy supply has grown at an average of 2.8 percent per year over the last 20 years, the same as the economic growth rate for the same period. Energy policy in Brazil in the last three decades has attempted mainly to reduce the country's dependence on foreign energy supplies and to stimulate the development of domestic energy sources, particularly from hydrocarbons. Over this period, natural gas and hydroelectricity production have increased steadily. The share of oil consumption decreased in the first half of the 1980s, but has been recovering since the oil counter-shock in 1986. Coal has increased, owing to the metallurgical sector, while biomass use has increased in the transport and industrial sectors, but decreased in the residential sector, owing to fuelwood substitution (Figure 2.2). Biomass for transport (ethanol from sugar cane) is very important in Brazil, with production of approximately 230 000 barrels of oil equivalent per day.

According to Brazil's Ministry of Mines and Energy (EPE, 2009), 11.6 percent of total primary energy supply (29.2 million tonnes of oil equivalent in 2008), as shown in Figure 2.1, is currently met by woodfuels, especially fuelwood and charcoal. Although woodfuels are important in the energy matrix, their consumption decreased until 2000, when the tendency reversed and started to increase quickly, taking only five years to regain the level of the late 1980s (Figure 2.3).

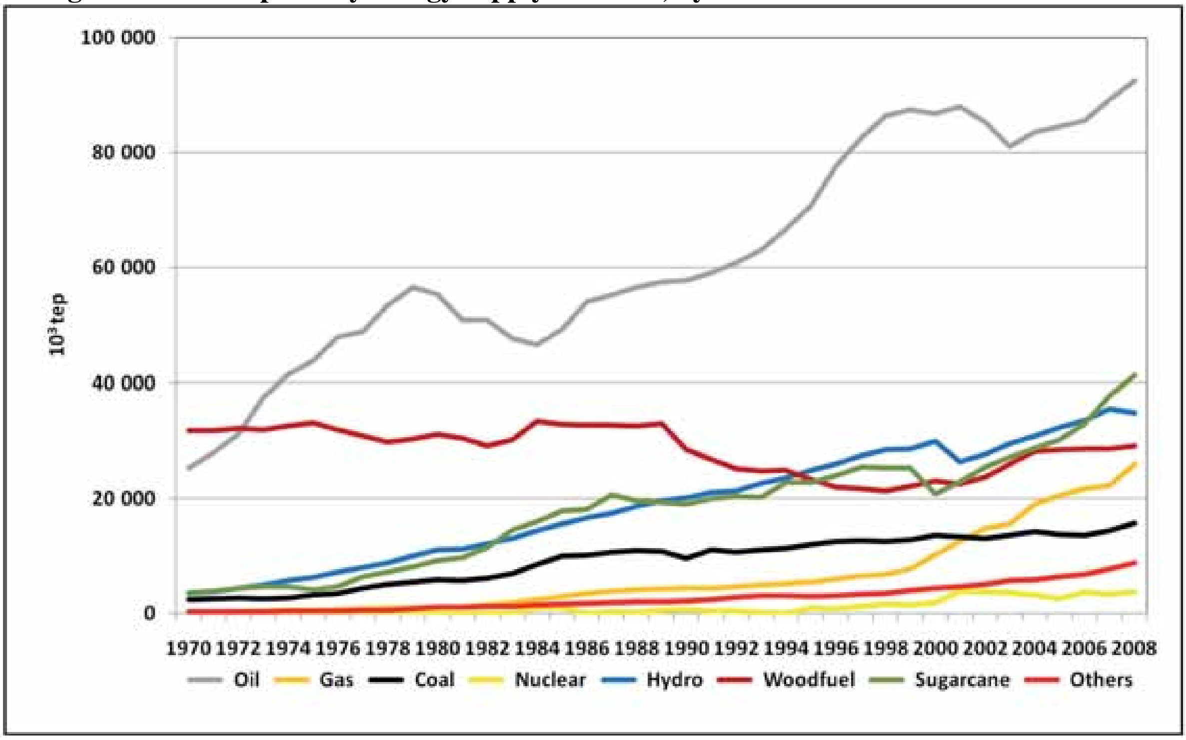
A strong boost to this trend reversal for woodfuel consumption was the increased conversion into charcoal, which is directly related to Brazil's increased pig iron production (Figure 2.4). About 42 percent of the 94.3 million tonnes of fuelwood consumed was converted into charcoal in 2008 (EPE, 2009), and charcoal is used almost totally by the industrial sector (Figure 2.5). However, these data were obtained from the National Energy Balance issued by the Ministry of Energy and Mines, and may present some methodological inconsistencies.

In the last 20 years, fuelwood demand has remained almost constant in the residential, industrial and agriculture sectors. Changes in consumption occurred in the transformation sector, where fuelwood is converted into charcoal. This product is directly related to the iron and steel industries, which accounted for 90.4 percent of total charcoal consumption in 2008 (EPE, 2009).

The use of woodfuels in Brazil's residential sector has changed notably over the past several decades. Fuelwood use for cooking and heating fell from 61.5 million tonnes in 1970 to 25.5 million tonnes in 2008 (EPE, 2009), although there are indications that high oil prices have recently reversed this trend. In the 1970s, 60 percent of fuelwood demand was for traditional cooking and heating uses in the residential sector. In 2008, fuelwood was still an important source of energy for food preparation, but accounted for only 27.1 percent of total use. Many poor households still rely predominantly on fuelwood to meet their cooking and heating needs, but there are important uncertainties about the consumption of fuelwood for residential uses, mainly owing to lack of information and the effect of the prices of possible substitutes, especially electricity and liquefied petroleum gas (LPG).

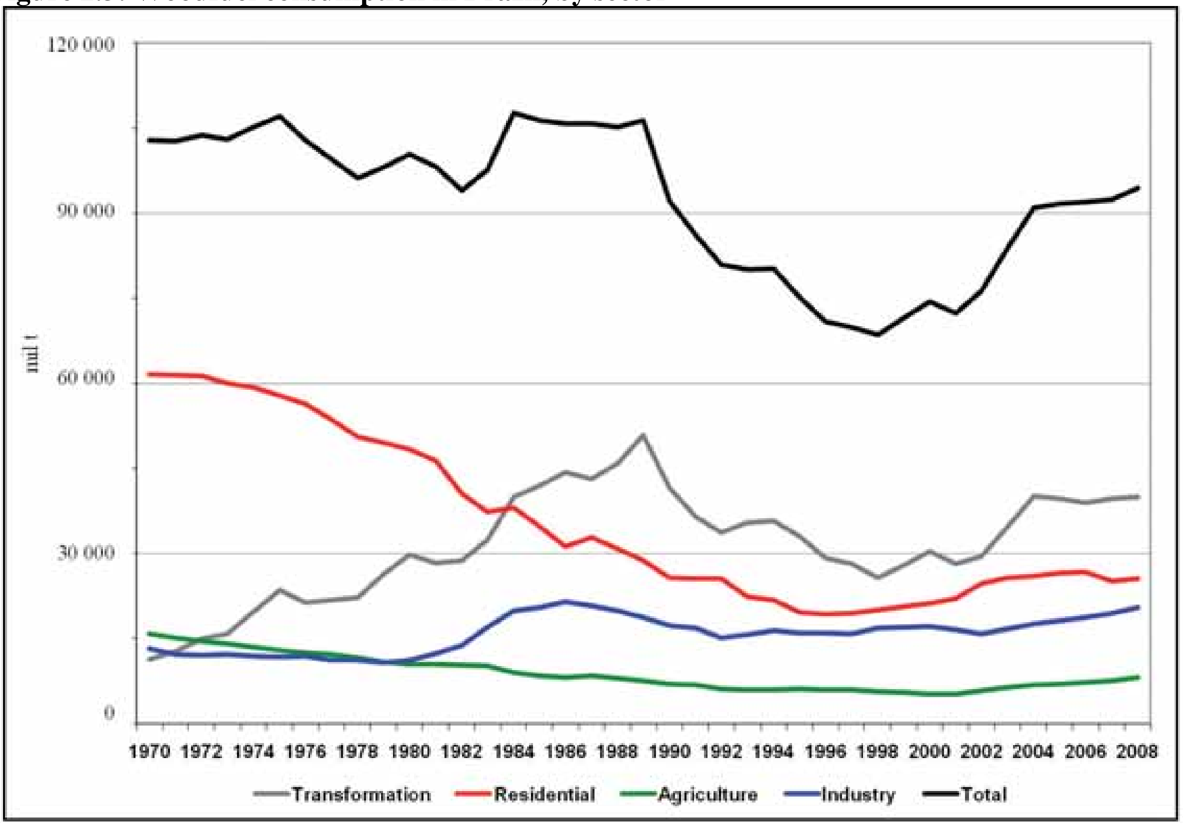
[1] The exchange rate on 30 October 2009 was R$1.76 = US$1.

Figure 2.2: Total primary energy supply in Brazil, by source



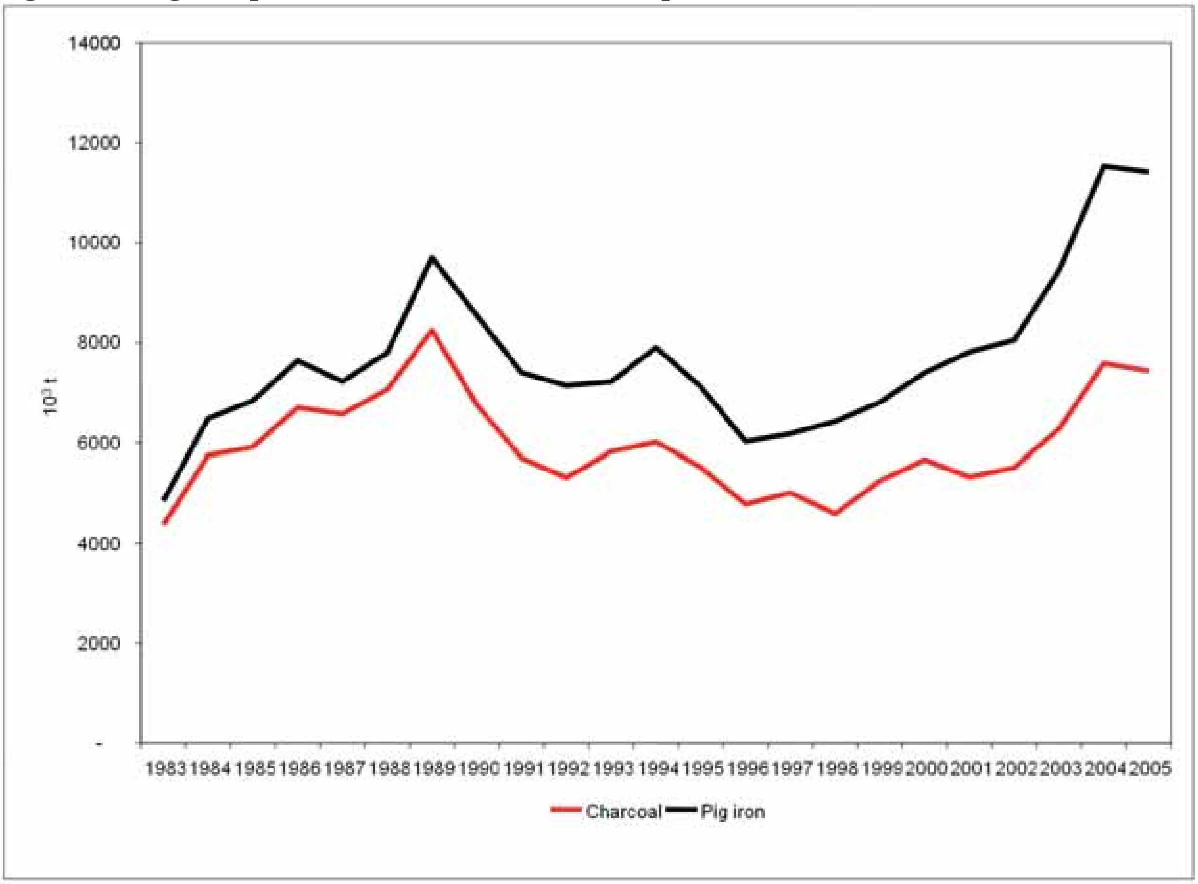
Sources: EPE, 2008; 2009.

Figure 2.3: Woodfuel consumption in Brazil, by sector



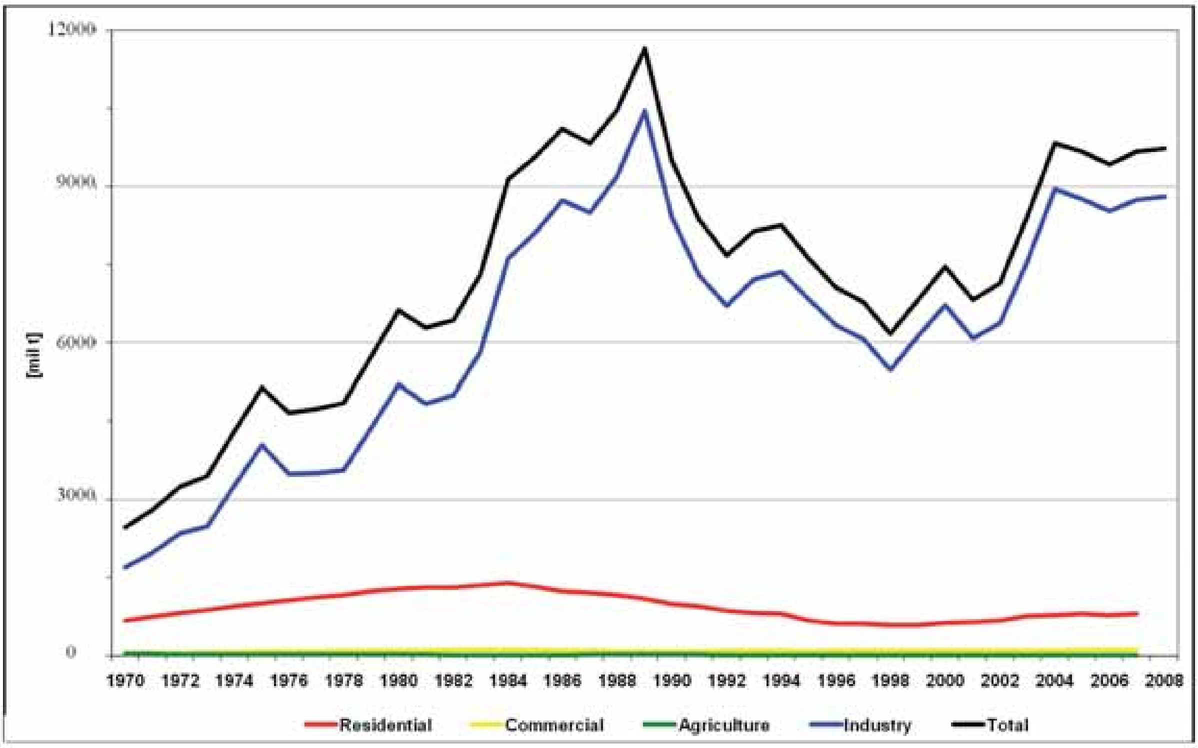
Sources: EPE, 2008; 2009.

Figure 2.4: Pig iron production and charcoal consumption in Brazil



Sources: SINDIFER, 2009; EPE, 2008.

Figure 2.5: Charcoal consumption in Brazil, by sector



Sources: EPE, 2008; 2009.

Only limited data are available, but according to the Ministry of Mines and Energy (EPE, 2008), per capita fuelwood consumption has stopped declining and started to increase, as many poor households are switching back to fuelwood in the face of high LPG prices. In some poor communities, inefficient stoves for burning wood residues are back in use after many years' absence. The evolution of fuelwood consumption in Brazil is presented in Figure 2.3. However, actual fuelwood demand may be lower than that indicated by official figures, which use rough estimation methods based on the evolution of LPG demand, affected by other factors such as stove efficiency and people's cooking practices. The fuelwood actually consumed in the residential sector is estimated to be half of the official figure (Uhlig, 2008) given in the National Energy Balance (EPE, 2008).

Although fuelwood consumption in the residential sector has decreased over recent years, a significant portion of the families using LPG also have fuelwood stoves, mainly in rural areas (Table 2.1).

Table 2.1: Households' fuel situation in Brazil, 2003

Fuel(s) used	Urban	Rural	Total	
	No. of households	No. of households	No. of households	% of total fuel use
Only LPG	31 916 473	2 480 533	34 397 006	68.5
LPG and fuelwood	3 007 274	4 096 489	7 103 763	14.1
Only fuelwood	462 382	1 312 046	1 774 428	3.5
LPG and charcoal	4 248 244	874 777	5 123 021	10.2
Fuelwood and charcoal	89 244	270 041	359 285	0.7
Only charcoal	323 916	311 889	635 805	1.3
LPG, fuelwood and charcoal	387 338	442 242	829 580	1.7
Total	**40 434 871**	**9 788 017**	**50 222 888**	

Source: IBGE, 2004.

In the last six years, the demand for charcoal has remained constant in the residential sector, which represents 8.3 percent of total charcoal consumption, with approximately 800 000 tonnes/year. An estimated 6.4 million households, 1.3 percent of the national total, consumed only charcoal for cooking in 2003 at practically equal levels in urban and rural areas, as indicated in Table 2.1 (IBGE, 2004). Although this percentage may be considered small, it means that 2.4 million people in Brazil relied on charcoal to prepare food. Charcoal consumption in the residential sector occurs mainly in the northeastern states, especially Maranhão and Piaui, where almost 20 percent of households in some municipalities use it for cooking. Owing to their location, the source of charcoal for these households is probably excess production from the charcoal kilns that supply pig iron production in Carajás Region of Pará and Maranhão States.

The high number of households, mainly in urban areas, that use both charcoal and LPG (Table 2.1) can be attributed to barbecuing, which is an important cultural feature across all income levels in Brazil. Bags of charcoal are sold in all supermarkets and at most gas stations, mainly for use in grills. In contrast with the residential sector, about which some information is available, fuelwood use in Brazilian agriculture, services and industries is not well-known, mainly because of the spatial distribution of these sectors. In the agriculture sector, fuelwood is used to dry agricultural products and produce animal feed, and in cottage industries, such as cassava flour houses and sugar cane processing mills. According to official figures, the agriculture sector used 8 million tonnes of fuelwood in 2008, corresponding to 8.6 percent of total fuelwood consumption in Brazil (EPE, 2009). However, using a different methodology, Uhlig (2008) estimated the agriculture sector's fuelwood consumption in 2005 to be 22.2 million tonnes.

The agriculture sector's charcoal consumption is not significant, at 11 000 tonnes, representing only 0.1 percent of the national total (EPE, 2008). However, as with fuelwood consumption, estimates differ, with Uhlig (2008) estimating charcoal consumption in the agriculture sector to be 84 000 tonnes, and the last agricultural census (IBGE, 2009a) estimating that agriculture consumed 37.2 million tonnes of fuelwood and 335 000 tonnes of charcoal in 2006.

In the commercial and services sectors, fuelwood and charcoal use are small, representing 0.3 and 1.1 percent of total woodfuel consumption, respectively, and used mainly in restaurants (EPE, 2008). These data must be taken with care, as they may be overestimated for some sectors, such as residential, and underestimated for others, such as industry and agriculture. In the industrial sector, fuelwood use represents 21.2 percent of total woodfuel consumption. The food (6.6 percent of total fuelwood consumption), pottery (6.6 percent) and pulp and paper (4.5 percent) industries are the most important fuelwood consumers. Food and ceramic industries are spread throughout the country, with plants of diverse capacities; the pulp and paper industry is more homogeneous.

The pulp and paper industry reflects the distribution of fuelwood production from forestry activities. Brazil manufactures pulp and paper from only planted forests of eucalyptus and pine, as confirmed by the distribution of wood consumption volumes for producing pulp, paper and fuel across Brazil's states (FAO, 2009). According to BRACELPA (2009), in 2007, the pulp and paper sector consumed 46.4 million cubic metres of wood for pulp and paper production, and 5.3 million cubic metres to produce energy. The wood used to produce energy was in the form of wood processing residues and black liquor.

The industrial sector consumed 8.8 million tonnes of charcoal, 90.4 percent of Brazil's total consumption. In 2007, the main consumers were pig iron production (76.4 percent), steel alloy production (9.9 percent) and cement making (3.6 percent) (EPE, 2008). The pattern of industrial charcoal consumption generally follows that of pig iron production, but there have been periods when charcoal consumption was much lower than pig iron production. This was probably owing to inaccurate information, as can be observed in Figure 2.3, where the values indicated do not maintain the same ratios. Another reason could be improved furnace technology and reduced losses. Nevertheless, changes in charcoal production and pig iron production are closely linked.

Brazil has two important metallurgical regions for pig iron and steel production: Maranhão and Pará States in the Northern Region, known as Carajás Region; and Minas Gerais State in Southeastern Region. These produced 3.5 million and 5.4 million tonnes of pig iron, respectively, in 2006, representing 93 percent of national pig iron production (SINDIFER, 2009). In Maranhão State, metallurgic companies expanded after the start of iron ore exploitation at Serra dos Carajás in 1981, and charcoal became the preferred energy for transforming iron ore into pig iron.

Woodfuel sources and deforestation

The fuelwood used in Brazil comes from native forests and forestry plantations. According to official figures (IBGE, 2009b), in 2008, 50 percent came from native forests. Fuelwood production from native forests is dispersed throughout the country (FAO, 2009), mainly because of residential use. According to figures for 1991, fuelwood production from native forest is more intensive in Acre and Pará in Northern Region, Bahia and Ceará in Northeastern Region, Mato Grosso in West-Central Region, and Paraná and Santa Catarina in Southern Region.

Charcoal production in Brazil is firmly based on the exploitation of native forests, despite the increasing importance of charcoal from planted forests. In 1990, 60.3 percent of Brazilian charcoal production was from native forests; in 2008, this percentage had decreased to 35.8 percent (IBGE, 2009b). It is important to observe the spatial distribution of charcoal production; production from planted forests occurs mainly in southeast Brazil.

The main charcoal producing states are Minas Gerais, Mato Grosso do Sul and Maranhão, which were responsible for 56.7, 14.6 and 7.8 percent, respectively, of national charcoal production in 2008 (IBGE, 2009b). This is mainly owing to the concentration of pig iron producing companies in these and neighbouring states.

During the 1990s, two trends were observed in the production of charcoal in northern Brazil: its declining role in deforestation, linked to increasing use of sawmill residues to produce charcoal; and the increasing distances between biomass sources and the sites of charcoal production for pig iron companies. The charcoal consumed in southeastern Pará and eastern Maranhão still comes from close to the pig iron plants, while that consumed in the southeast of Brazil is normally transported for more than 800 km to reach its users. Charcoal production from forestry plantations occurs near the biggest pig iron companies at Sete Lagoas Municipal District in Minas Gerais State, but not near those in the Carajás Region (FAO, 2009).

Brazil has the second largest forest area in the world (FAO, 2009), with 478 million hectares, 415.9 million hectares of which are primary forest, 57.3 million hectares modified natural forest, and 4.5 million hectares productive plantations. This represents a great resource, but about 0.8 percent of the total area is deforested every year (Table 2.2).

Table 2.2: Annual deforestation and regeneration in Brazil, 1988 to 1994

Biome	Deforestation (million ha)	Regeneration (million ha)
Amazonia	1.32	1.18
Cerrado	1.27	0.25
Mata Atlântica	0.08	0.03
Caatinga	0.34	0.00
Pantanal	0.14	0.05
Total	**3.15**	**1.51**

Source: Government of Brazil, 2004.

Typically, the cycle that makes wood available for use as fuelwood or charcoal begins with cleaning of the sub-forest and harvesting of trees, followed by the removal of wood for commercial use, fuelwood or transformation into charcoal. After this process, the residues are burned and used in pastures or soybean culture.

Future woodfuel supply and demand

Long-term studies are a fundamental element of a country's energy planning. In 2006, Brazil elaborated its first long-term study to examine the use of energy resources – the National Energy Plan, (PNE) 2030 (EPE, 2007). PNE 2030 provides the reference for the present study's analysis of woodfuel production and consumption, and its impacts on climate change in Brazil. On the demand side, the study formulates long-term scenarios for global economic evolution, and characterizes and quantifies scenarios for the Brazilian economy, including demographic projections. On the supply side, it covers research on available energy resources, the technical and economic features of different sources, and social and environmental aspects, as well as technological perspectives for energy production.

The scenarios define macroeconomic variables, along with energy demand and supply variables for Brazil and the world. Three global scenarios were defined (Table 2.3), and Brazilian scenarios were elaborated from these, taking into account the country's strengths and weaknesses in relation to the global contexts described in Table 2.3.

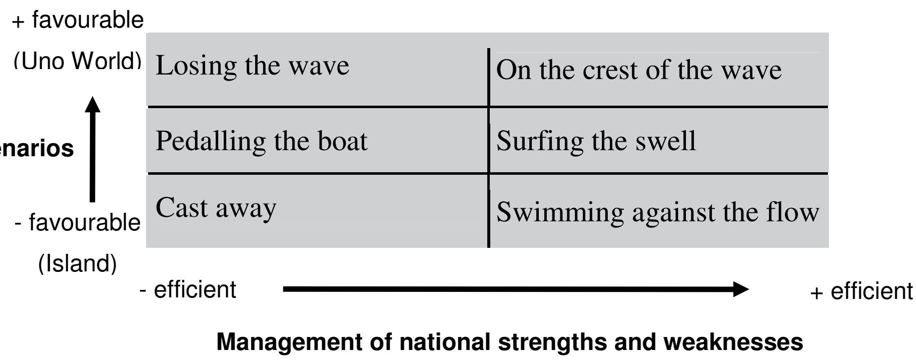
Table 2.3: Three global scenarios for woodfuel supply and demand

Factor	Scenario		
	Uno world	Archipelago	Island
Globalization pattern	Maximum connectivity: multilateralism	Partial connectivity: economic blocks	Interrupted connectivity: protectionism
Economic and political power structure	Balance of power and sharing of political power	Hegemony of blocks led by United States and European Union	Greater participation of Asian countries
	Coordinated macro-economic politics	Recovery of North American macro-economic balance through internal adjustment	Breakdown of China-United States trade, followed by slow economic recovery
Conflict resolution	Negotiated resolutions	Localized conflicts	Strong divergences

Source: EPE, 2007.

Formulation of the national scenarios considered the development of national competencies for seizing opportunities and defending against threats in the global environment, leading to the conception of six scenarios (Figure 2.6).

Figure 2.6: Brazilian national scenarios: key ideas



Source: EPE, 2007.

Selecting a smaller number of scenarios allows sufficient possibilities to be covered for long-term planning. Thus, the following does not consider the “Loosing the wave” and “Swimming against the flow” scenarios mentioned in Figure 2.6, as these lead to situations that are generally included in the others. The characterization of the four scenarios in PNE 2030 is summarized in Table 2.4.

Table 2.4: Brazil’s national scenarios for woodfuel supply and demand

Factor	Scenario			
	A – On the crest of the wave	**B1 – Surfing the swell**	**B2 – Pedalling the boat**	**C – Cast away**
Infrastructure	Important reduction of bottlenecks	Partially reduced bottlenecks	Permanent important bottlenecks	Effective disability
Income inequalities	Very important reduction	Significant reduction	Small reduction	Maintenance
Competitiveness	High and generalized earnings	Important but selective earnings	Unimportant earnings concentrated in few sectors	Low earnings concentrated in few sectors
Total economic productivity	High	Medium to high	Medium to low	Low

Source: EPE, 2007.

Projections of energy demand and supply for Brazil were proposed from the scenarios in Table 2.4. The basic differences among scenarios are due to externalities that may affect competition among energy sources or impose requirements to minimize environmental impacts. Thus, demand pressure in Scenarios A and B1, especially A, tends to elevate petroleum prices in the international market, creating conditions favourable for renewable energy sources; major market penetration by biodiesel is suggested. Multilateral agreements in the environment area (including the United Nations Framework Convention on Climate Change [UNFCCC] and the Kyoto Protocol) may also advance renewable energy sources.

However, the increased demand observed in scenarios of higher economic growth tends to counter this process of replacing traditional energy sources with other renewable or non-conventional ones. Even allowing for increased efficiency in energy final use, the demand in scenarios of more important growth becomes so much higher that the supply of energy from alternative sources cannot keep up, because the dynamics of growth in the different energy sources do not always differ much among the different scenarios. The general trends for Brazil considered in PNE 2030 were:

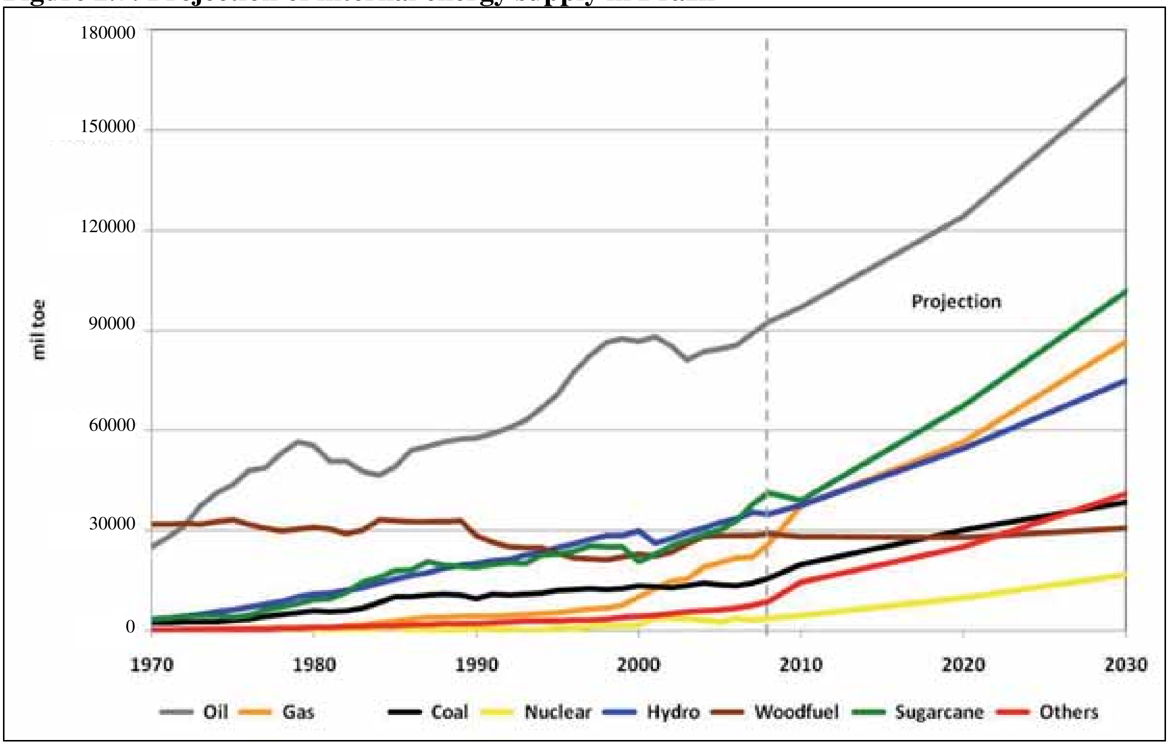
- → increased electrification;
- → increased use of natural gas to replace fuel oil, mainly in industry;
- → increased use of renewable liquid fuels (ethanol and biodiesel) to replace petroleum, mainly in agribusiness and the transportation industry;
- → growth of coal use as a reflex, mainly of steel expansion;
- → residual growth of fuelwood and charcoal, as evidence of the virtual exhaustion of the replacement process that occurred at the end of the twentieth century, limited to captive and controlled use of energy sources, respectively.

Under these macroeconomic scenarios, PNE 2030 notes that Brazil will have strong growth in primary energy demand over the next 20 years. The internal supply of energy is estimated to increase by 5 percent per year, from 2005 to 2010. However, this growth rate is estimated to decline to 3.6 percent per year for 2010 to 2020, and to 3.4 percent per year for 2020 to 2030, mainly owing to higher energy efficiency, on both the demand and supply sides (Figure 2.7).

Studies point to greater diversification in the Brazilian energy matrix. In 1970, only two energy sources (petroleum and fuelwood) accounted for 78 percent of total energy consumption, while in 2000 three energy sources addressed 74 percent of consumption (with the addition of hydro energy). In 2030, four major energy sources are projected to be responsible for 77 percent of consumption – petroleum, hydropower, ethanol (sugar cane) and natural gas – while the importance of fuelwood declines (Figure 2.7).

Another noteworthy finding is reversion of the trend for reduction in the share of renewable energy sources in the matrix. In 1970, this share was more than 58 percent, owing to the predominance of fuelwood. With the introduction of more efficient energy sources, mainly through the shift of fuelwood, it fell to 53 percent in 2000 and to 44.5 percent in 2005. This trend was maintained over the next years, but PNE notes the possibility for a reversal starting in 2010.

Figure 2.7: Projection of internal energy supply in Brazil



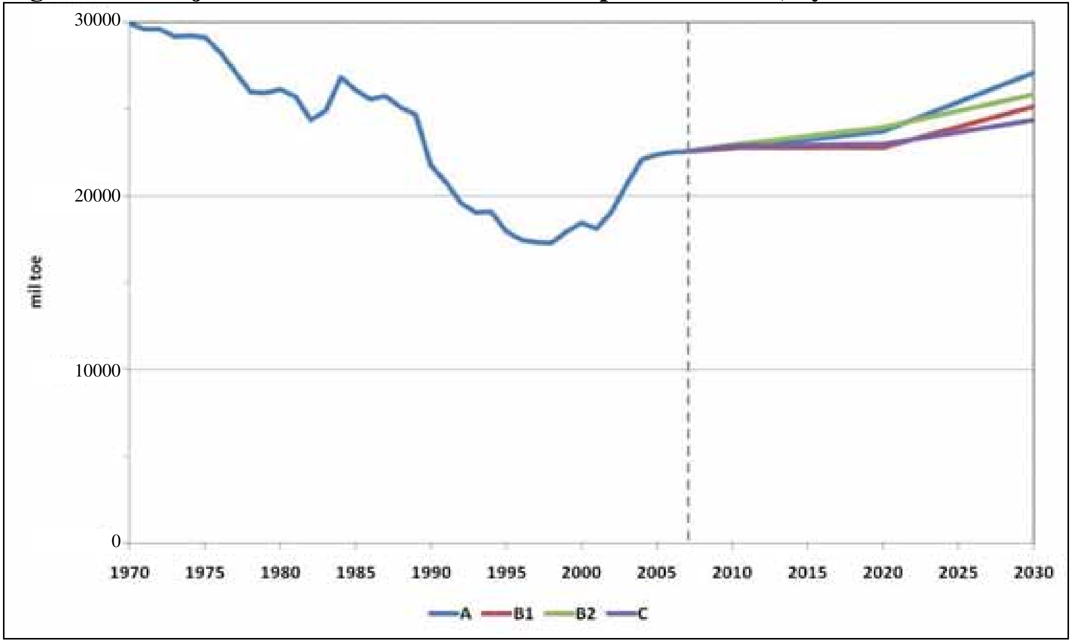
Source: EPE, 2007.

Woodfuel perspectives

The final consumption of woodfuel energy was projected for each of the macroeconomic scenarios (Figure 2.8). In 2030, woodfuel will have a smaller share than its current 11.6 percent, varying from 5.7 to 7.9 percent depending on the scenario. Although the quantity of woodfuel consumed in scenario A is greater, its relative participation is smaller, owing to growth in total energy consumption, which almost triples in this scenario; in the other scenarios, total energy consumption grows at lower rates.

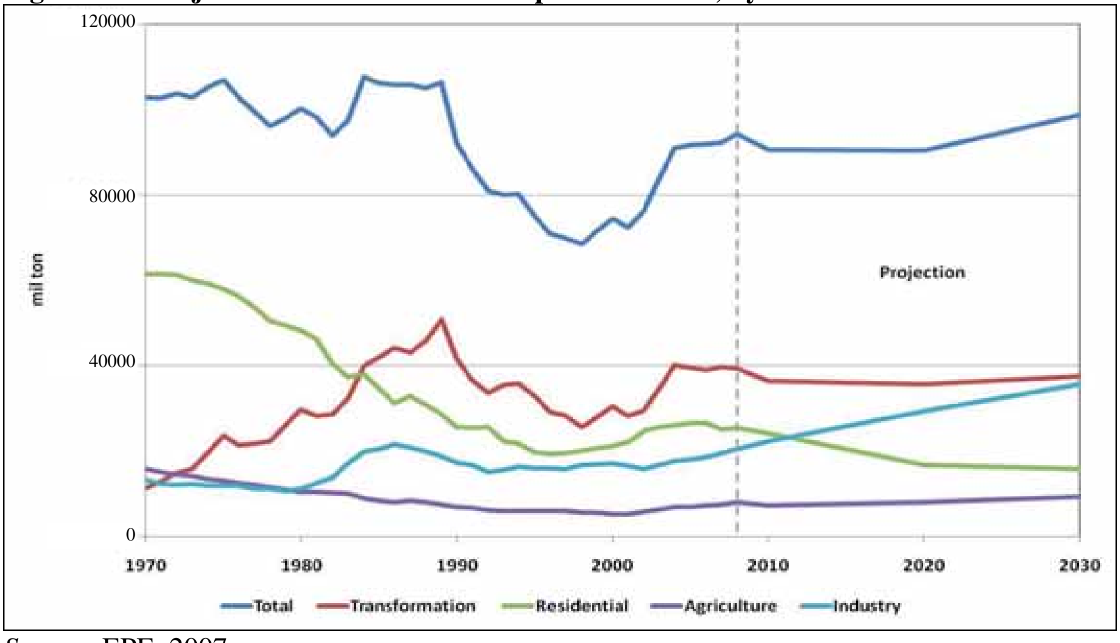
In all scenarios, consumption in the residential sector presents growth rates that are below the national average, although there are per capita increases. This trend may be attributed to increased energy efficiency, especially due to greater penetration of electric devices and the replacement of less efficient inputs such as fuelwood, which compensates for the growth in numbers of consumer devices in households (Figure 2.9).

Figure 2.8: Projection of woodfuel total consumption in Brazil, by scenario



Source: EPE, 2007.

Figure 2.9: Projection of woodfuel consumption in Brazil, by sector



Source: EPE, 2007.

In the industrial sector, the following measures will contribute to efficiency gains:

- → In the chemistry industry, the rate of natural gas penetration will increase, replacing such energy sources as fuelwood and fuel oil, for both steam generation in boilers and increased capacity for natural gas cogeneration.
- → In pottery, fuel oil and fuelwood consumption will be partially replaced with natural gas, depending on local restrictions on gas supply and the economic competitiveness of natural gas in relation to fuelwood.

Although the replacement of fuelwood with other energy types is projected, it is estimated that the industrial sector will increase its demand for woodfuel (Figure 2.9). Consumption of charcoal, which feeds most of the metallurgy industry, is projected to stabilize, given the likelihood that the carbon required for metallurgy expansion will be come from coal rather than charcoal.

Woodfuel and climate change issues

Status of and methodologies for national forest carbon inventories

One of Brazil's commitments under UNFCCC is to develop and periodically update national inventories of the anthropogenic GHG emissions from sources and removals by sinks that are not controlled by the Montreal Protocol, in addition to describing the steps taken or envisaged to implement the convention. The document containing this information is the UNFCCC National Communication.

The format of the Brazilian National Communication follows the guidelines contained in Decision 10 of the Second Conference of the Parties to UNFCCC (document FCCC/CP/ 1996/15/Add. 1 of 17 July 1996) *Communications from Parties not Included in Annex I to the Convention: Guidelines, Facilitation and Process for Consideration.*

Brazil's first National Communication is composed of three parts. The first part presents the national circumstances and special arrangements in Brazil, with an overview of the complexity of this immense country, and its development priorities. The second part comprises the first Brazilian GHG inventory for the period 1990 to 1994, which consolidates 15 sectoral reports from the energy, industry, forestry, agriculture and waste sectors, with additional information from participating institutions. The third part presents the steps envisaged or already taken that contribute directly or indirectly to achieving UNFCCC objectives.

Estimates from 1990 to 1994: As determined by UNFCCC, the inventory should include only those GHG emissions and removals that result from human (anthropogenic) activities. The inventory for 1990 to 1994 therefore considered emissions of CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Emissions were also estimated for the so-called indirect GHGs, such as nitrogen oxide (NO_2), carbon monoxide (CO) and other non-methane volatile organic compounds (NMVOCs). Emission of these gases was estimated for the following emission sources or sectors:

- → energy;
- → industrial processes;
- → solvent and other product use;
- → agriculture;
- → land-use change and forestry;
- → waste.

The inventory was developed according to IPCC guidelines and involved the Brazilian scientific and business communities, in addition to various government sectors. The results are presented in Table 2.5, which summarizes the estimates of GHG emissions for the base year of 1994, by sector.

Table 2.5: **Estimates of GHG emissions in Brazil, 1994 (million tonnes)**

Gas	Sector						
	Energy	Industrial processes	Solvent and other product use	Agriculture	Land-use change and forestry	Waste	Total
CO_2	236 505	16 870			776 331		1 209 706
CH_4	401	3		10 161	1 805	803	13 173
N_2O	9	14		503	12	12	550
HFC-23		0.157					0.2
HFC-134a		0.125					0.1
CF_4		0.345					0.3
C_2F_6		0.035					0.0
SF_6		0.002					0.0
NO_x	1 601	11		239	449		2 300
CO	12 266	510		2 787	15 797		31 360
NMVOCs	1 596	358	521				2 474

Source: Government of Brazil, 2004.

Brazil's emissions profile is different from that of developed countries, where emissions from fossil fuel combustion represent the greatest share. It was therefore necessary to develop adequate methodology to meet the needs for sectors that are important in Brazil, such as agriculture and land-use change and forestry. For these sectors, the emission factors provided by IPCC and used in the absence of national estimates may not reflect the Brazilian situation. Wherever possible, new studies were carried out in Brazil, and values significantly different from those suggested by IPCC were sometimes found.

Emissions of the main GHGs: In 1994, CO_2 emissions were estimated at 1 030 megatonnes, mainly from the land-use change and forestry sector, which accounted for 75 percent, followed by the energy sector, with 23 percent (Government of Brazil, 2004). CH_4 emissions were estimated at 13.2 megatonnes, with the agriculture sector responsible for 77 percent, followed by the land-use change and forestry sector, with 14 percent. N_2O emissions were estimated at 0.55 megatonnes, with the agriculture sector accounting for 92 percent. These estimates are discussed in the following paragraphs, by sector and subsector.

Energy sector: Anthropogenic emissions in this sector include those resulting from fuel combustion, and fugitive emissions in the chain of production, transformation, transmission and consumption. CO_2 emissions were the most important, totalling 237 megatonnes, mainly from fossil fuel combustion (98 percent), which increased by 16 percent from 1990 to 1994, reflecting an increase in consumption. CH_4 comes next, with 0.4 megatonnes, mainly (70 percent) from biomass burning (fuelwood, charcoal, etc.), which declined by 9 percent over the period because of reduced consumption. The greatest share of indirect GHGs was due to the road transport subsector. Most of these emissions (CO and NMVOCs) reduced significantly over the period because of technological improvements in the vehicle fleet.

Industrial processes sector: In this sector, estimates are made for anthropogenic emissions resulting from industrial production processes but not from fuel combustion. CO_2 emissions were again the most important, with 17 megatonnes, mainly from cement and lime production (80 percent), which did not change significantly. N_2O emissions, with 0.014 megatonnes, were due mainly to adipic acid production (96 percent), and increased greatly in the 1990 to 1994 period.

Solvent and other product use sector: Evaporation during solvent use generates emissions of NMVOCs, which reached 0.5 megatonnes in 1994.

Agriculture sector: In this sector, CH_4 emissions reached 10 megatonnes, owing to the enteric fermentation of ruminant herbivores (92 percent), which include the country's cattle herd, the second largest in the world. N_2O emissions totalled 0.5 megatonnes, and were due to various sources, including manure from grazing animals (43 percent). The practice of burning sugar cane before harvest was the main source of indirect GHG emissions in this sector.

Land-use change and forestry sector: Because of Brazil's massive national territory, estimation of values for this sector is one of the most complex parts of inventory preparation, and requires extensive assessments and use of remote sensing and statistical data from the forest inventory. Three sub-sectors are analysed:

→ Forest conversion to agricultural activities, or deforestation of native vegetation areas and forest regrowth from the abandonment of managed lands: Deforestation causes CO_2 emissions into the atmosphere, while regrowth implies the removal of CO_2.

→ Changes in the carbon content of soils, resulting from land-use changes such as forest conversion to agricultural and grazing lands and vice versa: Emissions from these changes depend on several factors: the land-use and soil management practices applied, assessed over a 20-year period; the application of limestone to correct acidity and enhance soil fertility; and the conversion of organic soils to agriculture, which causes rapid oxidation of organic matter. Carbon changes are associated with CO_2 emissions and removals.

→ Planted forests, especially industrial forests: This expanding activity results in increased biomass stocks. There are CO_2 emissions and removals in this subsector, with removals predominating.

Net emissions in this sector totalled 776 megatonnes of CO_2: 96 percent were attributable to forest conversion in agricultural and grazing lands; 10 percent were owing to changes in the carbon content of soils; and a reduction of 6 percent was due to removals by planted forests. Biomass burning for forest conversion to other uses was responsible for total emissions of 1.8 megatonnes of CH_4, in addition to indirect GHG emissions.

Waste sector: Solid waste disposal creates anaerobic conditions that generate CH_4. The emission potential of this gas increases depending on the control conditions in landfills and the depth of dumps. Waste incineration is not common in Brazil. Effluents with high organic content, such as domestic and commercial sewage, and effluents from the food and beverage industry and from the pulp and paper industry have high potential for CH_4 emissions. Emissions from this sector were estimated at 0.8 megatonnes of CH_4, an increase of 9 percent since 1990. Much of this was generated by solid waste disposal (84 percent). Domestic wastewater, because of the nitrogen content of human food, also generates NO_2 emissions, which were 0.012 megatonnes in 1994.

Carbon substitution policies

Although developing countries do not have commitments to reduce or limit their anthropogenic GHG emissions under UNFCCC, Brazil is developing programmes and actions that result in significant reductions of these emissions. Thanks to some of these initiatives, the country has a relatively clean energy matrix, resulting in fewer GHG emissions per energy unit produced or consumed. Several initiatives currently under implementation will also contribute to changing the curve of GHG emissions in the country.

In spite of these good results, however, Brazil faces two challenges: the difficult task of significantly reducing emissions from land-use change, and the need continuously to increase efficiency in the use of its natural resources.

These challenges will be addressed through coordinated, linked, continuous and synergic efforts under the National Plan on Climate Change (Government of Brazil, 2008), which defines actions and measures aimed at the mitigation of and adaptation to climate change. The plan has seven objectives:

i) promote increased efficiency by identifying better practices for the economic sectors;
ii) maintain the high share of renewable energy in the electricity matrix;
iii) encourage sustainable increases in the share of biofuels in the national transport matrix, and develop an international market for sustainable biofuels;

iv) achieve consistently declining deforestation rates in all Brazilian biomass, to reach zero illegal deforestation;
v) eliminate the net loss of forest coverage in Brazil by 2015;
vi) strengthen intersectoral actions aimed at reducing the vulnerability of populations;
vii) identify the environmental impacts of climate change, and promote scientific research.

The plan is based on the work of the Inter-Ministerial Committee on Climate Change and its Executive Group, established in 2007. Brazil's efforts are based on the commitment to reducing social inequality and increasing incomes through an economic dynamic with a low emissions trajectory.

Promote increased efficiency by identifying better practices for the economic sectors: To ensure sustainable national development, government actions for the productive sector must aim to establish increasingly efficient use of natural, scientific, technological and human resources. Stimulating better performance, based on best practices in each sector, will help reduce the carbon content of Brazilian GDP, improve the competitiveness of Brazilian products in international markets, and increase income and generate economic surplus that can lead to higher levels of social welfare. Efforts are also required in the area of energy efficiency and conservation, to reduce consumption, prevent increased electricity generation, and reduce GHG emissions.
Main actions:

→ Energy efficiency: Implementation of the National Policy for Energy Efficiency will gradually result in energy savings of up to 106 terawatts (TW) per year (10 percent of total electricity consumption) by 2030, avoiding emissions of around 30 million tonnes of CO_2 in that year.

→ Charcoal: Increased consumption of sustainable charcoal will replace coal in steel plants, mainly through the encouragement of forestation in degraded areas.

→ Fridges: For ten years, 1 million old fridges will be replaced per year, thereby collecting 3 million tonnes of CO_2 equivalents of ozone-depleting clorofluorocarbons (CFCs) a year.

→ Solar heating: Increased use of solar power water heating systems will reduce electricity consumption by 2 200 gigawatts (GW) per year, by 2015.

→ Replacement of refrigerant gases: An estimated 1 078 billion tonnes of CO_2 equivalents of hydro-clorofluorocarbons will be avoided between 2008 and 2040. Part of this will be offset by the emissions from substitute gases.

→ Urban solid waste: Recycling will increase by 20 percent by 2015.

→ Sugar cane: The use of fire for clearing and cutting sugar cane will be phased out in areas where mechanized harvesting can take place. To achieve this, every year mechanization will have to be adopted by at least 25 percent of the agro-industrial units in these areas. Agreements with the productive sector and cooperation with the states where this practice still occurs need to be established, and a monitoring system should be implemented.

→ Integrated agricultural and cattle raising systems: Incentives will be introduced for sustainable practices, with the aims of recovering a large part of the current 100 million hectares of degraded pasture; establishing carbon sinks via crop-livestock integration, agroforestry, or adoption of zero-tillage systems and reduced use of nitrogenous fertilizers; and enriching the organic content of pasture, to reduce methane emissions from cattle raising.

Maintain the high share of renewable energy in the electricity matrix: In comparison with other countries, Brazil has a low-emission energy sector, but one of its greatest challenges is sustaining this position in the face of growing demand for electricity. At present, 45.8 percent of the energy matrix consists of renewable energy, while the global average is 12.9 percent. For the electricity matrix, the percentage is an even more impressive 89.0 percent. The reference scenario in PNE 2030 (EPE, 2007) stipulates that expansion of the electricity supply between 2005 and 2030 will include 95 000 MW from hydropower plants. However, growing demand and the prospect of the long-term exhaustion of hydroelectric potential, in addition to socio-environmental issues, require that other sources also help drive this expansion, although hydropower should remain the priority. Among the alternatives available to Brazil are renewable energy sources – co-generation with sugar cane bagasse and other biomass, wind and solar – and other non-conventional sources, such as wastes.

Main actions:

- → Co-generation: Electricity from co-generation, mainly sugar cane bagasse, will provide 11.4 percent of the country's total energy supply in 2030, corresponding to 136 TW.
- → Non-technical losses in electricity distribution – which are currently about 22 000 GW per year – will decline by 1 000 GW per year over the next ten years, resulting in reduced energy wastage of 400 GW per year. On average, about 25 percent (100 GW per year) of this will no longer be produced by thermopower plants.
- → Hydroelectricity: 34 460 MW from new hydropower plants will be added to the system by 2016, in accordance with the work schedule in the Ten-Year Energy Plan 2007 to 2016 (EPE, 2007a).
- → Energy from wind and sugar cane bagasse: The share of these sources in the electricity matrix will be increased, with more than 7 000 MW being generated from renewable sources by 2010, in accordance with the Programme of Incentives for Alternative Sources of Electric Energy and the actions already carried out.
- → Photovoltaic solar energy: Efforts will be made to expand the national photovoltaic industry and the use of this energy source in systems that are isolated, which will be connected to the grid.

Encourage sustainable increases in the share of biofuels in the national transport matrix, and develop an international market for sustainable biofuels: Biofuels replace fossil sources that have a great impact on the climate and on air quality. Promoting the replacement of fossil sources in the Brazilian transport sector may lead to ethanol use increasing by an annual average of 11 percent in the coming years. The government is introducing the obligation to add 5 percent of this biofuel to diesel in 2010, instead of 2013. This will increase ethanol's share in the Brazilian transport matrix by more than 60 percent.

At the same time, technical cooperation with other countries with the agricultural potential for growing sugar cane aims to expand the supply of ethanol in the international market, making the market more stable and balanced and thereby allowing the sustainable expansion of demand. In this way, Brazil will contribute to the mitigation of GHGs beyond its own borders, while providing countries with predominantly agricultural economies with the opportunity to increase their export revenues.

Main actions

- → Ethanol: Increasing consumption by 11 percent per year over the next ten years, by producing it from crops raised in the areas defined in the current Sugarcane Zoning Programme, should prevent the emission of 508 million tonnes of CO_2 equivalents over this period.
- → Biodiesel: From 2010, 5 percent must be added to diesel.
- → Agro-energy: The National Agro-Energy Plan (Government of Brazil, 2006b) aims to carry out research, development, innovation and technology transfer to guarantee sustainability and competitiveness for agro-energy chains.
- → Stimulating the international ethanol market: Technical cooperation with other countries with a high potential for growing sugar cane will help stabilize and balance the market.

Achieve consistently declining deforestation rates in all Brazilian biomass, to reach zero illegal deforestation: The objective is to reduce deforestation by 40 percent between 2006 and 2009, based on the ten-year reference period of the Amazon Fund (1996 to 2005), and by a further 30 percent in each of the two following four-year periods, in relation to the previous four years. In the Amazon biome, achieving this objective would avoid emissions of about 4.8 billion tonnes of CO_2 between 2006 and 2017, based on a biomass carbon stock of 100 tonnes per hectare. This will be revaluated after completion of the carbon stock inventory supported by the National Forest Inventory.

Combating deforestation and providing incentives to stimulate economic growth in forested regions require large amounts of national and international resources, including those obtained by the Amazon Fund, both new and additional. The large numbers of variables to be controlled for reducing deforestation is another challenge. Despite constant monitoring and control, the demand for products that compete with the forest and for the timber produced from the forest oscillates over time. As a result, efforts can sometimes be satisfactory and at other times completely inadequate.

This is a challenging task and will require a government strategy involving more than traditional monitoring and surveillance actions. The Federal Government is making great efforts, such as the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon Region (PPCDAM), which resulted in a reduction of 59 percent in the annual deforestation rate in this biome for four consecutive years – 2004 to 2007. PPCDAM's central thematic areas are land and territorial organization, monitoring and control, and incentives for sustainable productive activities; the last of these is given priority in the guidelines of the Sustainable Amazon Plan. PPCDAM will be extended to other Brazilian biomass through the preparation of similar plans adapted to the specifics of each biome, and involving states, municipalities, civil society and the productive sector.

Main actions:

- → Implementation of the National Public Forests Register, created by the Brazilian Forestry Service: The register will identify public forests to be protected, preserved and managed, as the areas at greatest risk of deforestation and illegal occupation are those under unspecified land use.
- → Territorial and land organization, monitoring and control, and incentives for sustainable productive activities: PPCDAM and similar plans in other biomes aim to reduce the rate of deforestation, and involve partnerships among federal bodies, state governments, city governments, civil society organizations and the private sector.
- → High-precision monitoring: The Deforestation Monitoring Programme for the Caatinga, Cerrado, Mata Atlântica, Pampa and Pantanal biomes will use satellites, as are already used in Amazonia.
- → Strengthening environmental enforcement: The technical team responsible for enforcement will be increased through public competitions, specialized training and capacity development activities.
- → Amazon Fund: Created in 2008, the fund aims to raise financial resources nationally and internationally for reducing deforestation and increasing sustainable use and conservation, especially in the Amazon forest.
- → Climate Fund: Submitted to the National Congress, the fund's aims include financing actions to prevent deforestation.
- → Non-wood forest products: A minimum price policy has already been set for seven products (aimed at supporting traditional communities and peoples), to strengthen the productive chains that create wealth through the sustainable exploitation of native forests.

Eliminate the net loss of forest coverage in Brazil by 2015: In addition to the measures described for the previous objective, reforesting activities will also be encouraged. The purpose is to double the area of forest plantation from the current 5.5 million hectares to 11 million hectares by 2020, of which 2 million hectares will be planted with native species. Priority will be given to planting areas of degraded pasture, to promote their economic and environmental restoration. The positive impact of this objective can be measured in the carbon stocks inventory, supported by the National Forestry Inventory.

The intrinsic value of native forests is greater than that currently perceived for environmental services. Forests hold an incalculable genetic heritage, most of which is still unknown. Forest plantations, whether for the reconstitution of ecosystems or for economic use, create very significant environmental services, as they preserve water flows, reduce or prevent river and lake siltation, improve the micro-climate and allow the preservation of native species of fauna. Planted forests create products that can be used to substitute numerous non-renewable natural resources, such as coal and raw materials for civil construction, as well as reducing economic pressure on the native forests themselves. Among the reasons for stabilizing high levels of forestry coverage, forests' role as reservoirs of carbon should be stressed, as carbon stocks develop in vegetation and soil via CO_2 uptake from the atmosphere through the photosynthesis process. The annual forested area grew from 320 000 hectares in 2002 to 640 000 in 2007, while the share of small producers increased from 7 to 25 percent over the same period. However, to reach the objective, annual planting will have to be increased further, to reach 1 million hectares in 2011 and 1.2 million in 2015 (Government of Brazil, 2008).

In general, the forest land area should correspond to the sum of the areas to be conserved and those suitable for forestation or reforestation. These activities should be established wherever their environmental or economic returns are higher than the benefits from crops or animal breeding. Efforts will therefore be made to organize actions and mobilize instruments that can contribute to achievement of this objective, including the reforestation and forestation carried out under the auspices of the Clean Development Mechanism (CDM)), preserving the additionality of this important economic instrument. Lines of credit adapted to forestry activities, technical assistance and technological research will also be expanded.

Main actions:

- → Current banking requirements will be revised to make forestation and reforestation activities more attractive, including for charcoal production.
- → The recovery of degraded areas in legal reserves or areas of permanent preservation will be promoted, with resources from the national rural credit system providing low-cost funding.
- → The National Forest Inventory will provide information about all the country's forests, allowing maximum use of areas for reforestation and an evaluation of the carbon stocks.
- → Forestry products for fuel applications will be developed through the Energetic Forests Programme, coordinated by the Brazilian Agricultural and Livestock Research Company, with participation from the Brazilian Forestry Service through the Forest Product Laboratory, the Ministry of Development, Industry and Foreign Trade, various universities and research centres, and private enterprises. The programme works throughout the production chain, from forest to final product, contributing to the economic feasibility of forestation.
- → Forestry grant: Public forests concessions will be granted for the sustainable management and exploitation of forestry products and services. The Annual Forestry Grants Plan stipulated the concession of 4 million hectares by the end of 2009. A legal timber pact has been signed by the Ministry of the Environment and timber producers in the state of Pará.
- → Prevention of the use of illegal timber in the building industry: Starting in January 2009, building and real estate companies must prove the legal origin of the timber they use.

Strengthen intersectoral actions aimed at reducing the vulnerability of populations: The climate change process is a challenge to society and government sectors. The effects of this change on the population have many causal origins and diverse intensities, involving several sectors (cultural, educational, economic, social, etc.). Evaluation is complex and requires an integrated and interdisciplinary approach involving health professionals, climatologists, social scientists, biologists, physicists, chemists, epidemiologists and educators, among others, in analysing relations among social, economic, biological, ecological and physical systems and their relations to climatic alterations. The need to strengthen intersectoral actions results from the current vulnerability of many populations, which influences their capacity to respond to the consequences of climate change. Identifying the most vulnerable population groups and promoting actions to strengthen their resilience are fundamental for the creation of effective adaptation strategies. The lower the vulnerability of a system and the greater its capacity for self-organization, the getter its chances of adapting to the effects of climate change.

Main actions:

- → Incentives will be provided for studies, research and training to expand knowledge about the impacts of climate change on human health.
- → Environmental sanitation measures will be strengthened.
- → Communication and environmental education measures will be strengthened.
- → Threats, vulnerabilities and resources (financial, logistics, material, human, etc.) will be identified, to guide the development of prevention, preparation and response plans for public health emergencies.
- → Public health professionals' technical capacity regarding health and climate change impacts will be enhanced.
- → Warning systems for harm and damage related to climatic events will be created.

- → An information panel and indicators for the monitoring of climatic events and their impacts on health will be established.
- → Spaces for education and training in sustainable forest management will be established in existing school and university buildings, along with training of trainers and the appropriate curricula and teaching materials.

Identify the environmental impacts of climate change, and promote scientific research: Studies have been carried out to understand the regional dynamics of climate and the environmental, social and economic impacts – at both the national and local levels – that may occur as a result of climate changes in the coming century. Efforts will be made to increase scientific knowledge about all aspects of these issues, to achieve adaptation that minimizes the socio-economic costs of changing climatic conditions for Brazil.

Main actions:

- → The Climate Network, which brings together numerous research centres from all over the country, will be strengthened to carry out studies on the impacts of climate changes, focusing on Brazil's vulnerabilities and the adaptation of solutions for social, economic and natural systems, and to guide the formulation and monitoring of public policies and mitigation actions for climate change.
- → The capacity to develop and assess regional climate change scenarios will be enhanced to include long time scales using the supercomputers of the National Space Research Institute, which will contribute to studies on vulnerability and adaptation for South America.
- → Partnership between the Ministry of the Environment and the National Space Research Institute will be established for implementation of the Warning System for Droughts and Desertification.
- → Hydro-climatic models for large river basins will be developed, the National Water Agency's situation room for monitoring critical events will be strengthened, conservation activities and the optimization of water use will be promoted, and the national system for monitoring water resources will be strengthened to promote more efficient use of freshwater.

The Brazilian National Plan on Climate Change (Government of Brazil, 2008) defines actions for the mitigation of and adaptation to climate change, but it lacks details about how objectives will be achieved and the costs of doing so.

Potential for and costs of woodfuel substitution and emissions reduction

Potential for woodfuel substitution and emissions reduction

Brazil has 478 million hectares of forest area, of which 415.9 million hectares are primary forest, 57.6 million hectares modified natural forest, and 4.5 million hectares productive plantation. Although these are abundant and renewable resources, PNE 2030 (EPE, 2007b) and the National Agro-energy Plan 2006 to 2011 (Government of Brazil, 2006b) do not encourage the production and use of woodfuel, instead they emphasize other biofuels such as sugar cane products. To estimate the potential for woodfuels to replace fossil fuels:

- → the sectors that use the most fossil fuels were identified, enabling their replacement;
- → the replacement potential was estimated, and the differences among the final use outputs of different fuels were calculated;
- → the planted or native forest necessary to fulfil the demand from fossil fuel replacement was calculated;
- → the avoided GHG emissions were estimated;
- → the cost of replacing fossil fuels with woodfuel was calculated;
- → estimates were made for 2007 and 2030.

The sectors: The sector with the most possibilities for replacing fossil fuels with woodfuel is the industrial sector. Analysis of this sector identified three activities that use fossil fuels on a large scale and where a share of these fuels could be replaced by woodfuel: metallurgy, pulp and paper, and pottery. Metallurgy is responsible for 22.3 percent of industrial energy consumption; of this, 55.1 percent comes from fossil fuels and 26.2 percent from woodfuel, in this case, charcoal (EPE, 2008). Pulp and paper activities are responsible for 10.43 percent of industrial energy consumption, with 12.5 percent from fossil fuels and 68.4 percent from woodfuel, in this case fuelwood and black liquor (EPE, 2008). Pottery is responsible for only 4.7 percent of industrial energy consumption, but it is also the area presenting the greatest potential for replacement, as 33.1 percent of its energy comes from fossil fuels and 49.1 percent from woodfuel, in this case fuelwood (EPE, 2008). The food and beverage industry consumes the most energy in the industrial sector, with 26.0 percent, but 75.8 percent of this comes from sugar cane residues, so replacement with woodfuel would not be worthwhile (EPE, 2008).

Replacement of fossil fuels with woodfuel was not considered for the residential, commercial and farming sectors. In the residential and commercial sectors, fossil fuels are used for cooking, and it would be difficult to replace them with wood. Woodfuel handling and delivering are complex tasks, and residential and commercial users are unwilling to give up the comfort and quality of life that the use of fossil fuels allows; wood collection is a strenuous and time-consuming activity. In the agriculture sector, fossil fuels are used for transportation and, to a small extent, in grain drying (1 percent). Woodfuel is already widely used for grain drying (26 percent), which decreases the possibilities for replacement (EPE, 2008).

Replacement potential: Based on the analysis of data about the sectors, final uses and familiarity with woodfuel use, a portion of the fossil fuel (natural gas, metallurgical coal, fuel oil, coke, coal and petroleum coke) used in each sector was replaced with woodfuel (charcoal and fuelwood) (Table 2.6). The same replacement rate was considered for both 2007 and 2030, as the data used in PNE 2030 (EPE, 2007b) do not consider more intense use of woodfuel. When fossil fuels are replaced by woodfuel and liquid, and gas fuels by solid fuels, the performances of equipment used for direct heating or heat provision decline. The differences in equipment performance considered in the analysis are shown in Table 2.7. For metallurgy, equipment performance grows by similar proportions in 2007 and 2030; for the pulp and paper subsector, the performance of solid fuel boilers grows more than that of liquid fuel boilers; and for pottery, the performance of liquid or gas fuel ovens grows more than that of solid fuel ovens.

Table 2.6: Replacement of fossil fuels by woodfuel in Brazil, by industrial activity

Activity	2007 (%)	2030 (%)
Metallurgy	30	30
Pulp and paper	20	20
Pottery	30	30

Table 2.7: Differences in the performance of equipment resulting from the replacement of fossil fuels with woodfuel in Brazil, by industrial activity

Subsector	Performance difference2007 (%)	Performance difference2030 (%)
Metallurgy	14.7	14.3
Pulp and paper	14.3	9.8
Pottery	37.5	66.7

Source: Government of Brazil, 2006b.

Potential impacts of replacing fossil fuels with woodfuel

In the conditions described in the previous section, it is possible to replace 3.8 million tonnes of petroleum with woodfuel in 2007, and 9.7 million tonnes in 2030, representing 4.7 and 5.4 percent of total energy consumption in the industrial sector in 2007 and 2030, respectively. For such replacements, 26.1 million tonnes of woodfuel are needed in 2007 and 66.5 million tonnes in 2030.

Forest area required: It was considered that 20 percent of the wood needed for increased demand in 2007 comes from the sustainable exploitation of native forests, and 80 percent from planted forests. In 2030, 10 percent comes from native forests, and 90 percent from planted forests, with protection of native forests remaining at its current level. Based on average productivity levels for Brazilian native and planted forests, in 2007 the increased demand for woodfuel requires the sustainable exploitation of 1.1 million hectares of native forests, or 1.2 percent of the existing resource, and the planting of 522 000 hectares of forests, an 11.6 percent increase on the current planted area of 4.5 million hectares (IBGE, 2009). This requires change of use on 0.5 percent of the land currently used for pasture.

The requirements for 2030 are the sustainable exploitation of 1.5 million hectares of native forests, or 1.6 percent of those existing in 2007, and the planting of 1.5 million hectares, an increase of 33.3 percent on the planted area in 2007. This requires the conversion of 1.5 percent of the land currently used for pasture. Although Brazil has a large area of pasture and underused land (101 million hectares) (IBGE, 2009), which could be used for the expansion of reforested areas with species suitable for energy use, there is a risk that forest energy plantations would exert pressure on native forest areas or areas dedicated to food production. In addition, permission for the sustainable exploitation of forests representing up to 14.2 percent of the total area (in the case of low productivity) could lead to permission for the clear-cutting of forests.

Avoided emissions: The replacement of fossil fuels with woodfuel generates reductions of 14.2 million tonnes of CO_2 equivalents in 2007, and 35.5 million tonnes in 2030. This is equivalent to 0.6 percent of current total Brazilian emissions (2.2 billion tonnes of CO_2 equivalents; McKinsey & Company, 2009) and 7.9 percent of those from the industrial sector (179.7 million tonnes of CO_2 equivalents); 80 percent of Brazilian emissions are due to deforestation and agriculture (McKinsey & Company, 2009). In 2030, total Brazilian emissions are projected to grow by 28 percent, to more than 2.8 billion tonnes of CO_2 equivalents (McKinsey & Company, 2009), and the replacement of fossil fuels with woodfuel will reduce this by 1.3 percent, while industrial emissions of 358.6 million tonnes of CO_2 equivalents will be reduced by 9.9 percent. In spite of the Brazilian government's commitment, GHG emissions from deforestation and agriculture will remain stable but continue to represent 71 percent of the total (McKinsey & Company, 2009).

Calculations of GHG emissions are based on the reference values for 1994, the year of Brazil's last emissions inventory (Government of Brazil, 2004), to which was assigned a zero net contribution of woodfuel. In addition to the positive and negative impacts listed in the previous subsections, the replacement of fossil fuels with woodfuel can also provoke increased emissions from the transportation of woodfuels. Unlike fossil fuels such as natural gas and fuel oil, which are transported by pipeline, woodfuels are transported by road, sometimes for long distances.

Cost of replacing fossil fuels with woodfuel

The cost of replacing fossil fuels with woodfuel in the scenarios described in the previous sections is US$247.6 million,[2] or US$17.42 per tonne of CO_2 equivalents. For metallurgy, the figures are US$468.9 million in total, or US$37.15 per tonne of CO_2 equivalents. For pulp and paper, preventing emission of 566 000 tonnes of CO_2 equivalents costs US$80 million, or US$141.41 per tonne of CO_2 equivalents. For pottery, the costs are more attractive, at US$141 million for reductions of 1 million tonnes of CO_2 equivalents, or US$137.92 per tonne. These values were estimated from the average market prices of fossil and woodfuels in 2007: US$40.00 per tonne for coal, and US$160.00 per tonne for coke. Although the

[2] The exchange rate on 30 October 2009 was R$1.76 = US$1.

replacement of fossil fuels with woodfuel is competitive for metallurgy, using the November 2009 European Climate Exchange prices, it would cost US$20.00 per tonne of CO_2 equivalents.

The 2030 scenario is based on higher coal and coke prices (four times their 2009 levels; World Coal Institute, 2009). Prices of oil products, fuel oil and petroleum coke are expected to fall, so prices of 50 percent less than 2009 values were used. Natural gas prices are expected to remain stable, and woodfuel prices to increase by 50 percent. In 2030, the industrial sector will therefore require US$1.3 billion, or US$35.74 per tonne of CO_2 equivalents, to replace fossil fuels with woodfuel. In all activities, the replacement will represent financial gains: for metallurgy of US$920 million, or US$29.00 per tonne of CO_2 equivalents; for pulp and paper of US$103.6 million, or US$103.70 per tonne of CO_2 equivalents; and for pottery of US$85.2 million, or US$85.20 per tonne of CO_2 equivalents.

Conclusions and recommendations

This paper has analysed woodfuel and its potential for substituting fossil fuels in the metallurgy, pulp and paper, and pottery industries, and suggested the investments required for successful substitution. Although wood is an abundant and renewable resource in Brazil, its availability for all uses, including energy, is limited. Woodfuel from native and planted forests remains a relevant source of heat in Brazilian industries and households, providing about 11.6 percent of the country's total primary energy. With planning and incentives for the sustainable use of woodfuels, their use to replace fossil fuels may represent an important way of reducing GHG emissions, mainly in the industrial sector.

The use of woodfuels is important in the metallurgy, pulp and paper, and pottery industries, which over the years have replaced wood with fossil fuels because of the scarcity and high prices of wood. The return to woodfuels could generate reductions of 14.2 million tonnes of CO_2 equivalents in 2007, and 35.5 million tonnes in 2030. Compared with total Brazilian emissions in 2005 (2.2 billion tonnes of CO_2 equivalents; McKinsey & Company, 2009), the reduction in 2007 is not very high, at only 0.6 percent. However, this also represents 7.9 percent of industry emissions.

The cost of replacing fossil fuels with woodfuels in these three industries in 2007 is US$247.6 million, or US$17.42 per tonne of CO_2 equivalents. In 2030, it is US$1.3 billion, or US$35.74 per tonne of CO_2 equivalents.

In spite of wood's importance to Brazil, and its potential to decrease GHG emissions, the country is doing little to promote this energy source and encourage forest plantations for energy use. It is remarkable that such a relevant source of bioenergy is virtually absent from energy plans and discussions, such as PNE 2030 (EPE, 2007b) and the National Agro-energy Plan 2006 to 2011 (Government of Brazil, 2006b).

With its great potential for exploiting native forests and forestry for energy, Brazil should improve its policy and actions in this field, to promote the renewability, sustainability and protection of forest resources associated with energy, environmental and climate policies. Policy guidelines should be drawn up for the expansion of woodfuel production and for increased efficiency in conversion processes and final uses. Although the wood energy chain is made up of private stakeholders, the government should play a central role, launching initiatives and setting regulatory, economic and fiscal directions in a National Policy for Wood Energy. The following proposals are based on the suggestions of the Brazilian Institute of Energy Efficiency (INEE, 2006):

- → A national wood energy information system should be organized, with methodologies and resources to survey, watch and guide wood use and prepare an annual wood balance, if possible at the state level. This will identify the hot spots where woodfuel is unsustainable and deserves more attention.
- → Market studies and improved statistics on the supply of and demand for woodfuels are essential.
- → There is need to define long-term targets and schedules for increasing production and reducing costs of the wood – both planted and deriving from wood industries – used directly as an energy source or transformed into secondary forms, such as charcoal.

- → As well as continuing ongoing forestry research in universities and elsewhere, it is also important to investigate and document the status of forests and woodlands, to identify areas under stress.
- → Adequate conditions must be created for scientific and technological development in forestry and wood energy processes, to strengthen national expertise in the production, conversion and management of wood energy systems for different uses and capacities.
- → Norms and standards for wood energy systems should be developed, defining the conditions for promoting efficiency, reducing losses and increasing sustainability.
- → Innovative sources of charcoal should be studied.
- → Research in increasing the combustion efficiency of charcoal is also important. This will promote better charcoal production and techniques for recovering and using by-products, to reduce the emissions from charcoal production and valorize wood as a raw material.

A desirable forest policy would promote an increase of forested area in Brazil and develop forest management and exploitation according to modern ecological strategies. Care must be taken to prevent the extensive use of wood from putting pressure on native forests and leading to increased illegal logging. Actions taken to reduce illegal deforestation include broader surveillance, operations to combat corruption in the authorization of logging, management of landownership, and creation of protected areas. These activities have helped to reduce fraud and bribery, but trained personnel and full legal enforcement are still required.

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3. Woodfuel development and climate change mitigation in India

Devendra Pandey

Introduction

Biomass from forests and trees has remained the principal source of domestic energy in India. In the context of climate change, biomass is considered an important source or sink of CO_2, the most abundant of the GHGs. IPCC estimates that forestry and land-use change accounts for nearly 20 percent of global CO_2 emissions (IPCC, 2007), while India's First National Communication estimated it to account for less than 2 percent of national net emissions in 1994 (Ministry of Environment and Forests, 2004), with activities in the energy sector contributing about 85 percent, and industrial processes about 13 percent. According to estimates, removals of CO_2 via sinks were from only forestry and land-use change, and were about 3 percent of the total emissions. There is much scope for enhancing removals through conservation, proper forest management and the establishment of tree plantations, which would contribute to mitigating climate change. Not only would this neutralize all the net emissions due to forestry and land-use change, but it could also partly offset emissions due to the burning of fossil fuels to meet India's energy needs. Biomass-based electricity generation is a carbon-neutral option for power generation leading to no net emissions. Large quantities of woodfuels can be produced sustainably through the recycling process (growing and harvesting).

The burning of fuelwood (a major woodfuel[3] in which the wood's original composition is preserved) – mainly by households, for cooking and heating, but also by hotels, restaurants and cottage industries and for human cremation – is the main contributor to net emissions from forestry. In 2004/2005, when the last survey was conducted, about 75 percent of household energy in rural areas was met from woodfuel (NSSO, 2007). For rural and urban households combined the percentage was 60. From 1999 to 2004 only 1 percent of rural households switched from woodfuel, compared with about 3 percent in 1994 to 1999. Most of these households switch from woodfuel to LPG use, the availability and accessibility of which have gradually increased since the 1990s. Although the percentage of the population consuming woodfuel has declined substantially over the last decade and a half, the absolute number has continued an upwards trend owing to population growth.

Although woodfuel is the largest use for wood in India, and in most developing countries, its production, supply, distribution and consumption have remained mainly in the informal sector. Unlike fossil fuels and electricity, there are almost no reliable records from which to derive production and consumption data (Pandey 2002). There is therefore much uncertainty concerning quantities consumed and sources of woodfuel supply. The many studies of woodfuel in India have tended to focus on consumption as household energy, estimating per capita consumption in different segments of the population, rather than examining the sources of supply.

Recently, total production has been calculated from estimates of consumption and expert judgements by the Forest Survey of India (FSI, 2009b). Estimated woodfuel production was about 261 million cubic metres in 2005, against industrial roundwood production of 46 million cubic metres. Production increased from 213 million cubic metres in 1990 to 245 million in 2000. In the past, it was estimated that most woodfuel is derived from forests, resulting in their overexploitation and degradation. However, recent estimates contradict this, as a lot of woodfuel is produced outside the forests from trees growing on homesteads, farmland, the sides of roads, railways and canals and common lands.

[3] Woodfuel includes all types of biofuels derived directly and indirectly from trees and shrubs grown on forest and non-forest lands, and includes fuelwood, charcoal, black liquor and others (FAO, 2004).

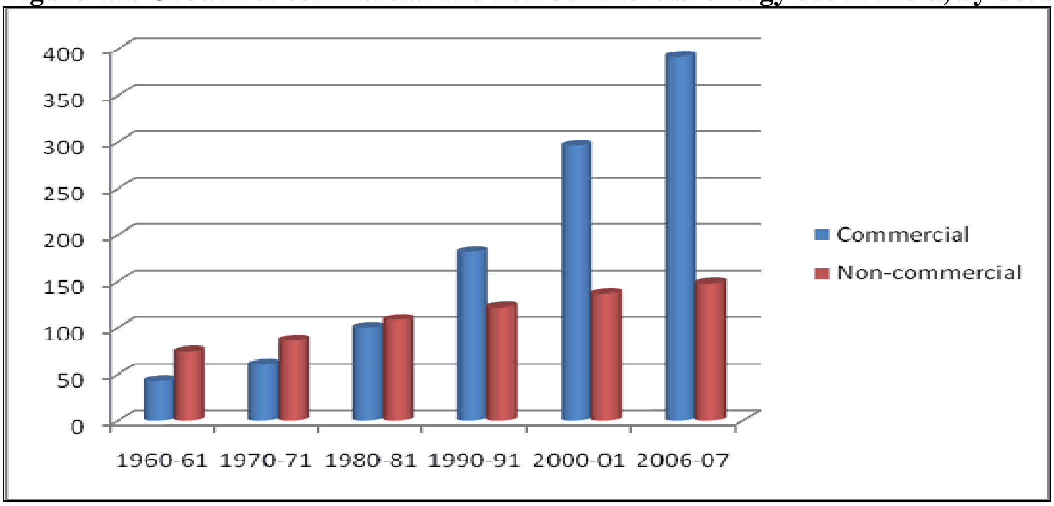
Overview of energy use

Energy is one of the critical inputs for the economic growth of any country. Per capita income is strongly correlated with the per capita consumption of energy in both developing and industrialized countries. In 2007, per capita consumption of energy in India was one of the lowest in the world, at 530 kg of oil equivalent compared with a world average of 1 820 kg (IEA, 2009). Per capita consumption of electricity is also far below that of other countries, and access to electricity is very uneven. Although 85 percent of India's villages are electrified, about 57 percent of rural and 12 percent of urban households – representing approximately 44 percent of the country's total population – did not have electricity in 2000. Those with access to electricity suffer shortages and poor quality of supply (IEA, 2006). To bring qualitative and quantitative improvements to India's energy sector, an Industrial Policy Resolution was announced in 1991, promoting private participation in the energy sector and enhancing investment and competitiveness in what was hitherto a monopoly of the public sector.

There has been a steady rise in energy production in India over the last five decades. Total energy production increased 4.5-fold between 1960 and 2007, rising from 117.2 million tonnes of oil equivalent in 1960/1961 to 539.09 million tonnes in 2006/2007. This growth is mainly in commercial energy (coal, lignite, oil, natural gas, hydropower, nuclear power and wind power) which increased ninefold, from 42.82 million to 391.53 million tonnes of oil equivalent, while production of non-commercial energy (woodfuel, agricultural waste and dung) only doubled. Non-commercial energy's share in total energy declined from 64 to 27 percent from 1960 to 2007. The eleventh Five-Year Plan (2007 to 2012) aims to enhance the production of commercial energy by about 40 percent and that of non-commercial energy by 14 percent. Figure 4.1 shows the growth of commercial and non-commercial energy production in India.

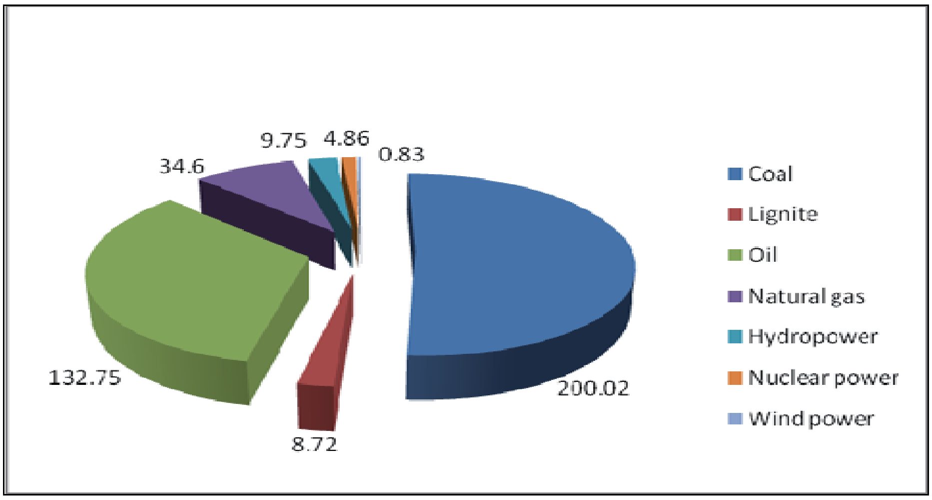
Regarding the sources for commercial energy production, although the share of oil and gas has been progressively increasing, from 8.29 million tonnes of oil equivalent in 1960 to 167.4 million tonnes by 2007, coal continues to be the dominant source, with a share of more than 50 percent. India's total coal production was 430.54 million tonnes in 2006/2007, with associated lignite of 30.63 million tonnes for this period. The two other important sources of commercial energy are hydro and nuclear power, which are used mainly for electricity generation. Figure 4.2 shows the sources for commercial energy.

Figure 4.1: Growth of commercial and non-commercial energy use in India, by decade



Years are financial years: 1960/1961 runs from April 1960 to March 1961.
Source: Planning Commission of India, 2008.

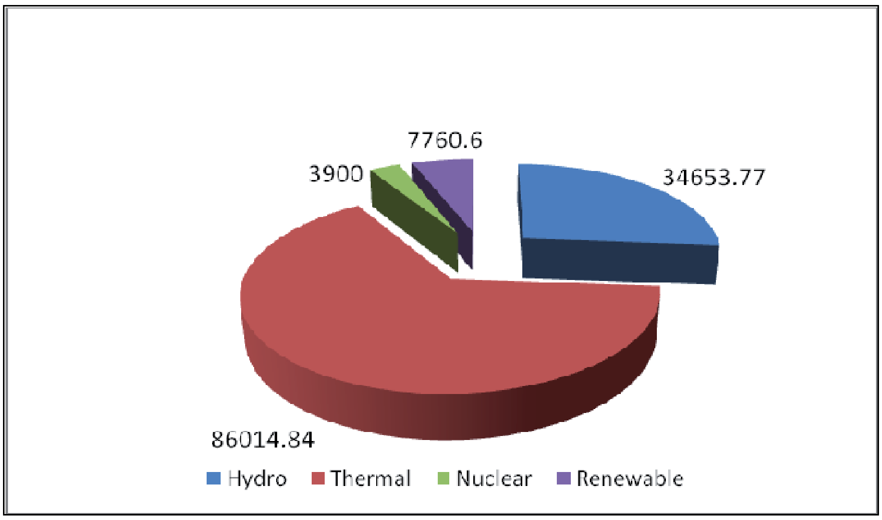
Figure 4.2: Sources of commercial energy in India, 2006/2007 (million tonnes of oil equivalent)



Enhancing electricity generation is near the top of the government's agenda, because electricity is one of the most convenient forms of energy and its availability is directly linked to the country's economic growth. During the tenth Five-Year Plan (2002 to 2007), the installed generation capacity was increased by 21 080 MW, bringing the cumulative capacity at the end of the plan (2007) to 132 329.21 MW. The contributions of different energy sources were 26 percent hydro, 65 percent thermal, 3 percent nuclear, and about 6 percent renewable (Figure 4.3). Renewable energy includes wind power and biomass-based plants. The private sector accounts for about 13 percent of total electrical energy production.

The demand for oil and gas has been consistently rising in India owing to the increasing population and the lifestyle demands of consumers, particularly for natural gas, because of its clean and environmentally friendly image. However, the domestic production of crude oil has not been increasing in tandem with demand, and remained at about 32 million tonnes per year from 1995 to 2005. Annual production of natural gas has been also static, at about 32 billion cubic metres from 2004 to 2008. The gap between demand and supply is filled by imports of oil and gas, which are equivalent to about 70 percent of total demand. Many potential sites of oil and gas have been explored since the New Exploration Licensing Policy was launched, but production has not yet started. Overall production is expected to double in next five years.

Figure 4.3: Contributions of different sources to electricity generation in India, 2007 (MW)



Historically, India has been energy-constrained and has resorted to imports to bridge the gap between demand and supply. Dependence on imports has grown, and they supplied about 33.7 percent of total primary commercial energy consumption in 2006/2007. The major share of imports are of oil to meet the demand for petroleum products. About 73 percent of total demand for oil and petroleum products was met from imports in 2006/2007. About 13 percent of coal for the steel industry was also imported. Recently, non-coking coal for power utilities and the cement industry, and LPG for the power and fertilizer sectors have also been imported (Planning Commission of India, 2008).

Impacts of developments in the commercial energy sector on woodfuel consumption

Developments in the commercial energy sector have affected consumption patterns for woodfuels. The most significant impact has been due to growth in the petroleum sector, which has increased the availability of LPG and kerosene, the two preferred substitutes for woodfuel for households' cooking needs. Since the Indian LPG market opened up to private retailers, there has been phenomenal growth in the LPG supply, from 18.1 million connections[4] in 1992 to 54.2 million in 2000, reaching 110 million in 2009. This had had an impact on both urban and rural households. Percentage increases in the use of LPG by rural and urban households are shown in Table 4.1.

Table 4.1: Percentages of households using LPG in India

Households	1994	2005
Rural	1.9	8.6
Urban	29.6	57.1
Total	**7**	**23**

Although the government provides subsidies to offset part of the increase in international prices, the price of LPG has risen over the years. However, its use in even lower-middle-income and poor households continues to grow. In many states, schemes have been launched to extend LPG connection to rural areas with reduced quotas for subsidized kerosene, by opening extension counters in rural areas within 15 km of urban distributors' normal trading areas. Some state governments provide grants for poor people to meet the initial cost of buying gas stoves, etc. As LPG is the most convenient and cleanest form of energy, its popularity is likely to grow, as long as it is readily available.

Electrical energy use in the household sector is mostly for lighting, and partly for heating and water heating during winter. The increasing availability of electrical energy in rural areas is replacing kerosene (for lighting) to a great extent. Between 1994 and 2005, 18 percent of households switched from kerosene to electricity (NSSO, 2007). Electricity is also replacing some woodfuel use for winter heating in poor households and for cooking (making tea, heating water, etc.). Although no reliable data are available, people in rural areas where electrical energy is available are now often seen using electrical heaters and tea makers instead of woodfuel. More affluent urban households also use electrical energy for cooking, and many large cities have established electricity-driven crematoria. The growth of electrical energy has thus reduced the use of woodfuel.

In India, coal is used mainly for generating electricity and in the metallurgical, brick making and other industries. Coal has had a major impact on the brick making industry, where it has replaced woodfuel, thus reducing the use of woodfuel, but quantified information is not available. However, growth in the coal sector has little direct impact on households' use of energy, as it is not a preferred energy source.

[4] A household usually has one connection with either one or two LPG cylinders, each containing 14.2 kg of LPG.

Current woodfuel consumption and supply sources

Although woodfuel remains the most important source of household energy in India, no regular studies and analyses of it have been made at the national or regional level. One of the main reasons for this is that historically woodfuel has been gathered free of cost, and production and consumption aspects have received little attention. The occasional studies that have been carried out are mainly by the research institutions of local or state planning boards, and sometimes by state forest departments. The most significant contributions have been made by two national institutions: the National Council of Applied Economic Research (NCAER), an autonomous body; and the National Sample Survey Organization (NSSO), a government organization dedicated to socio-economic surveys. NCAER conducted two[5] sponsored studies on household energy consumption, including woodfuel, during the late1970s and in the early 1990s, focusing on the consumption of kerosene and LPG (for the Indian Oil Corporation) and improved cooking stoves (for the Ministry of Non-conventional Energy), respectively. NSSO assesses the costs of a variety of household energy sources used for cooking and lighting, as part of the consumer expenditure survey it conducts every five years. This does not include the quantity of woodfuel consumed, however. Pandey (2002) provides a detailed summary of all the woodfuel studies carried out in India. The NSSO surveys seem to be the only new studies carried out since 2002.

The accuracy and validity of woodfuel statistics depend on how the data are collected and analysed. Among the most important considerations are the criteria used for stratifying the population, the proximity to accessible forest resources, urbanization level, income level, and local climate. Coverage of a cross-section of the population, the sampling design followed, the rationality of assumptions, and the method and duration of data collection also influence the reliability of woodfuel statistics. Per capita energy consumption of households in different population strata is the most crucial factor for estimating total consumption in a region or at the national level.

The latest NSSO study, completed in June 2005 (NSSO, 2007), provides the basis for the best estimate of total energy consumption in India's household sector. No regular surveys cover woodfuel consumption in other sectors, such as hotels and restaurants, or cottage industries. The results of a few local-level studies have been extrapolated to derive national estimates for these sectors. About 60 percent of all the rural and urban households in India depend on woodfuel and account for 95 percent of total woodfuel production, of 248 million cubic metres (Table 4.2).

The per capita consumption in rural and urban areas of different regions, as recorded by NSSO, were first converted into consumption per household and then multiplied by the number of households in each stratum, to give average per capita woodfuel consumptions of 17.7 kg in rural areas and 6.3 kg in urban areas.

Different calculations were carried out to estimate the consumption of woodfuel in the other three categories. For cremation, average death rates, broken down by religion, were taken from the Central Statistical Organization. Cremating a human body requires an average of about 0.3 tonnes of woodfuel, in the form of logs. Total woodfuel consumed for cremations was estimated from the total population, the annual death rate and the average fuelwood required for cremating one body. In 2005, an estimated 6.91 million people died among the four religions that use cremation (Hindu, Sikh, Jain and Buddist). Total fuelwood required for cremation was therefore 2.07 million tonnes or 2.96 million cubic metres (Table 4.3).

Table 4.2: Percentages of households using different forms of energy in India, 2005

Form of energy	Rural	Urban	Combined
Fuelwood and chips	75	21.7	60
Dung cake	9.1		6
Kerosene		10.2	2.9
LPG	8.6	57.1	23
Agricultural residues, coal, coke & others	6	6.1	6
Other	1.3	4.9	2
Total	**100**	**100**	**100**

[5] These two studies cover a large number of woodfuel consumption parameters.

The estimated fuelwood consumed in cremations is about 1.15 percent of total woodfuel consumption. Ranganathan, Subba Rao and Pandey (1993) estimated that the equivalent figure for cremations in Karnataka State was about 1.5 percent, while West Bengal Forest Department (1987) derived a figure of only 0.7 percent for cremations in West Bengal. At the national level, an estimate of about 1 percent seems reasonable, given the partial switch to electric crematoria in many major cities of India. (This aspect is not taken into consideration in Table 4.3.)

Estimates of consumption by hotels and restaurants were based on the results of two studies: one carried out in 1984/1985 by West Bengal Forest Department (1987), and the other in 1984 by Gujarat Forest Department (Pinto, Khanna and Pandey, 1985). In West Bengal, hotels and restaurants were found to use about 3 percent of total woodfuel consumption, but in Gujarat the figure was only about 2 percent. Considering the partial switch to commercial energy in the period since these studies were made, 2 percent can be assumed as the national estimate.

The same two studies were also used to estimate fuelwood use by cottage industries (brick making, etc.). Both studies found that fuelwood consumption by cottage industries was about 2 percent of the total. This has been assumed as a valid national estimate.

Table 4.4 shows the breakdown by sector of total woodfuel consumption of 261 million cubic metres. Other studies give very varying estimates for woodfuel consumption in sectors other than households. For example, in Haryana (NCAER, 1988), other sectors accounted for about 11 percent of total woodfuel consumption, whereas in Jammu and Kashmir (Government of Jammu and Kashmir, 1987) the figure was 3.5 percent. Given the energy transitions that have occurred since these studies were carried out, a national estimate of 5 percent for all other sectors seems reasonable. In India, charcoal is generally used in urban areas by food vendors and blacksmiths, to heat irons for pressing clothes, as a conditioner in heavy clay soil, and in a wide range of other industries. National data on its consumption are not available, but total charcoal consumption at the national level is estimated at 1 percent of total household energy consumption, equivalent to 2.61 million cubic metres or 1.90 million tonnes (ESMAP, 1999; 2001; Ranganathan, Subba Rao and Prabhu, 1993).

Table 4.3: Population, death rate, number of deaths and woodfuel use for cremation in India, by religion

Religion	2001 (million)	2005 (million)
Hindu	827.6	887.3
Muslim	138.2	148.2
Christian	24.1	25.8
Sikh	19.2	20.6
Buddist	7.9	8.5
Jain	4.2	4.5
Others	6.6	7.1
Total population	**1027.8**	**1102**
Hindu, Sikh, Jain and Buddist population	858.9	920.9
Annual death rate (per 1 000)	8.4	7.4
Total deaths (million)	7.21	6.91
Fuelwood consumed* (million tonnes)	**2.16**	**2.07**

* At 0.3 tonnes per cremation.

Table 4.4: Total woodfuel consumption in India, 2005

Sector	Annual consumption (million m^3)	% of total
Households	248	95
Hotels and restaurants	5.2	2
Cremations	2.6	1
Cottage industries	5.2	2
Total	**261**	**100**

Traditionally, forests were considered the main source of woodfuel, which the people living on forest fringes collected and transported themselves. Many earlier fuelwood studies assumed that this was the only source of woodfuel, and did not carry out in-depth analysis of any other supply sources. More recently, however, studies indicate that forests supply only a limited quantity of woodfuel. NCAER (1985) found that 26 percent of woodfuel came directly from forests, 17 percent from roadside trees, 27 percent from markets (which could be supplied from forests, own trees or other sources), 26 percent from own trees, and the remaining 4 percent from unknown sources. Based on NSSO data on the free collection of fuelwood, only 25 percent of freely collected and 20 percent of total fuelwood in India came from forests. Taking this estimate as the most accurate, the production of woodfuel from forests is calculated to be 52 million cubic metres (FSI, 2009b), with the remaining 209 million cubic metres coming from farmland, community land, homesteads, roadsides, canal sides and other wasteland. The supply of charcoal comes mainly from *Prosopis* and *Acacias* trees growing on wasteland (non-forest).

Wood energy potential

Historically, natural forests were considered the primary source of wood energy, and excessive woodfuel collection from forests has been assumed to be the chief cause of forest degradation. Since 1979, India has implemented social forestry programmes, focusing mainly on increasing woodfuel production by planting trees on community wastelands, marginal farmlands and other vacant land along roads, railways and canals. External aid agencies such as the World Bank, the United States Agency for International Development (USAID) and the Swedish International Development Cooperation Agency (Sida) provided financial assistance. Most of these programmes ensured people's involvement by setting up village social forestry committees.

Annual afforestation reached its peak at about 1.8 million hectares between 1985 and 1990. When the externally funded projects ended, tree planting continued under new government initiatives, at a similar rate of about 1.5 million hectares per year. Under a grant aid scheme, the government granted funds for tree planting by non-governmental organizations (NGOs). Many autonomous bodies such as the National Dairy Development Board and the Indian Farmers' Fertilizer Cooperative started to support tree planting.

Major government initiatives included integrated afforestation and ecodevelopment projects and area-oriented fuelwood and fodder projects, which continued until the end of the ninth Five-Year Plan in 2002. A new National Afforestation Programme was launched under the tenth plan, integrating all the previous afforestation schemes (Ministry of Environment and Forests, 2005). This programme is implemented through a decentralized institutional mechanism in which forest development agencies are established by the state governments to allow greater community participation in the planning and implementation of appropriate afforestation programmes. Since the 1980s, the cumulative area under various afforestation schemes exceeds 42 million hectares, but the lack of a robust monitoring and survey mechanism means that the areas of successfully afforested land, their productivity, status and locations are not known. However, the increase in industrial timber and woodfuel production from trees outside forest indicates that these programmes have had a positive impact. Current woodfuel production estimates suggest that more than 75 percent of India's wood energy comes from trees outside forests, on homesteads, farmland, alongside roads, canals and railways and on other common lands.

Land availability

India is a densely populated country with 324 people per square kilometre. The pressure on land is very high (land-use statistics are given in Table 4.5). Of India's total territory of 328.7 million hectares, only about 183.5 million hectares can be cultivated for expanding forests and growing trees. Although net shown area under agriculture is only 141 million hectares, other cultivable lands are under some type of cultivation or encroachment, and only small patches are available for raising woodfuel. India's economy is based on agriculture, so agricultural land cannot be converted into land for wood energy.

India's current forest cover is about 69 million hectares, representing about 21 percent of the total area; 45 percent of it is degraded. The National Forest Policy (1988) emphasizes the maintenance of environmental stability and ecological balance, including atmospheric equilibrium, vital for the sustenance of life forms – human, animal and plant. The generation of direct economic benefits is of secondary importance to this principal aim (Ministry of Environment and Forests, 1988). The current estimate of 52 million cubic metres of woodfuel from forests is already not a sustainable yield, so it is not feasible to use forest land for the commercial production of wood energy.

Table 4.5: Land use in India, 2006 (million hectares)

Geographical area	328.7
Reported area	305.8[1]
Forests	69.7
Not available for cultivation	42.2[2]
Permanent pastures	10.5[3]
Miscelleneous tree crops and groves	3.4
Cultivable wasteland	13.2
Current fallow	14.8
Other fallow	11.2
Net shown area	140.9

[1] Land-use statistics for 23 million hectares are not available, as approximately 12 million hectares is under Pakistan and Chinese occupation and the rest is under permanent snow or in inaccessible regions.
[2] Includes areas of construction – roads, railways and settlements – cities and villages.
[3] Most in high-altitude alpine regions.
Source: Department of Agriculture and Cooperation

Little land is available for wood energy production in India. During implementation of the National Forestry Action Programme (1993 to 1999), state forest departments identified about 21 million hectares outside forests where afforestation could be undertaken in combination with other activities (Ministry of Environment and Forests, 1999). However, landowners were not consulted, so no progress in this has yet been made. Wastelands and other vacant and degraded parcels of land can be identified from satellite imagery, but growing wood for energy in combination with agricultural cropping seems to be the best option.

Opportunities for the private sector

The private sector should play the main role in increasing the production of wood energy outside forests. Cultivable land with potential for growing trees for both timber and wood energy is available within the private sector, which is currently estimated to produce more than 80 percent of the industrial wood in India. However, the private sector's potential for growing trees has not been fully realized because innovative policies and support from appropriate financial policy instruments are lacking. Laws and procedures regarding the cutting, transportation and sale of privately owned trees must be simplified, as they currently constitute a major disincentive for growing trees. Where government forests are absent or minimal, and the risks of timber theft from public forests are negligible, restrictions on the cutting, transportation and sale of privately owned trees should be abolished. Market mechanisms and linkages between production systems and user groups should be developed to ensure reasonable prices for private wood energy producers. There has been little research on growing trees for wood energy in India. Investments should be made in research on raising trees with multiple benefits, including the production of wood energy. There is need for effective extension mechanisms through the establishment of model plantations, technology promotion campaigns, the distribution of attractive extension literature, and media publicity to support farmers and other landholders interested in growing trees for multiple benefits.

Biomass from tree plantations

The cumulative mitigation potential of renewable energy technologies is estimated to range from 12 to 15 percent of the overall power sector's mitigation potential in India (Shukla *et al.,* 2002). Biomass and co-generation technologies account for more than 60 percent of total mitigation by renewable energy technologies in CDM. Crop residues and agricultural waste are the main raw materials for biomass energy, but wood energy has high potential. Examples of the biomass production potential of fast-growing tree species are given in the following paragraphs.

Eucalyptus tereticornis hybrid has been planted extensively in India on a wide variety of lands, including denuded and barren lands. A review of published data on *E. tereticornis* shows that its standing biomass ranges from 11.9 tonnes per hectare in three-year-old plantations to 118.2 tonnes per hectare at six years in moist tropical conditions; and from 5.65 tonnes per hectare at five years to 112.5 tonnes per hectare at eight years in dry tropical regions (Rawat *et al.,* 2008). Most of these studies were done during 1970s and early1980s on a very small scales and results have to be treated as only indicative.

Studies of biomass production have also been carried out for other species in semi-arid areas under high-density energy plantations. Kimothi (1984) studied biomass production from seven species grown in non-irrigated conditions. The results are shown in Table 4.6. *Dalbergia sissoo* and *Prosopis juliflora* produced the maximum total biomass of 114 tonnes of dry matter per hectare at three years of age. Of this, utilizable biomass was 88.9 tonnes for *P. juliflora* and 84.1 tonnes for *D. sissoo*, giving annual productivity of 29 and 28 tonnes per hectare, respectively. Productivity of utilizable biomass from eucalyptus was about 14 tonnes per hectare. As these were experimental plantations, they were managed particularly carefully and it may not be possible to achieve the same productivity from large-scale routine plantations. However, a range of 5 to 10 tonnes per hectare per year can be assumed to be reasonable. An estimated 45 000 MW can be generated sustainably from about 2 million hectares of wasteland yielding 10 million tonnes per hectare per year from woody biomass, generating 4 000 kilocalories per kilogram at 30 percent system efficiency (Planning Commission of India, 2008).

Hooda *et al.* (2007) conducted a case study to assess the carbon mitigation potential of eucalyptus under agroforestry systems in Uttarakhand. A comparison of six-year rotation eucalyptus for bioenergy with ten-year rotation eucalyptus grown as a carbon sink shows that carbon abatement is higher in the former. The study projected that plantations grown for energy needs could meet 5 to 24 percent of India's total projected energy consumption in 2010.

Table 4.6: Biomass production by seven species grown on energy plantations in India, at different periods of growth (oven-dry tonnes per hectare)

Species	1 year	2 year	3 year
Eucalyptus hybrid	5.00 (2.3)	29.42 (17.4)	66.54 (43.5)
Albizia lebbeck	10.28 (5.6)	29.63 (7.0)	70.80 (51.5)
Dalbergia sissoo	10.70 (6.2)	49.08 (34.2)	114.54 (84.1)
Acacia nilotica	16.34 (11.1)	45.93 (31.6)	85.26 (68.5)
Cassia siamea	12.52 (7.2)	45.54 (30.1)	86.10 (63.7)
Acacia tortilis		37.77 (27.7)	87.41 (71.7)
Prosopis juliflora		41.39 (32.2)	114.61 (88.9)

Figures in parenthesis represent utilizable biomass, including bole and branch wood.

Technology and human resources

Wood for energy is produced mainly as a by-product of forests and trees outside forests. As in the example of biomass production from eucalyptus discussed previously, production can be for both commercial purposes and mitigating climate change. This requires research into standardized methodologies for high productivity and technologies for converting woodfuel into a convenient and easy form of energy to use. The suitability of specific tree species for different agro-ecological regions and the methodology for maximum (utilizable) biomass production (spacing and treatment) also have to be researched. A good background for such research is already available in India, and can be expanded. As well as from government institutions, useful inputs for enhancing productivity have also come from the private sector, such as WIMCO Seedlings, The Energy Research Institute (TERI) and ITC Bhadrachlam Paperboards Pvt Ltd (Pandey and Pandey, 2004).

The Ministry of New and Renewable Energy is responsible for promoting technology for converting and using woodfuel efficiently and conveniently. Smokeless and fuel-efficient stoves have been designed, and biomass gasifiers are already in use. According to the ministry's latest data, energy production from biomass (mostly agro-based and bagasse) and gasifiers was about 2 210 MW in July 2009. For technical and economic reasons, the producers of biomass power prefer to use woodfuel as raw material, but sustainable woodfuel supplies are not available.

Private sector companies such as TERI have made significant contributions to developing and disseminating technology, especially biomass gasifiers for small- and medium-scale industries. Ovens, kilns and furnaces based on biomass gasifier technology have also been developed for industries. Currently, more than 440 TERI gasifiers, with cumulative capacity of about 40 MW, are operational in the silk reeling, textile dying, cardamom curing, natural rubber processing, chemical extraction, metal smelting and mineral processing sectors. These systems have allowed fuel savings of about 50 to 60 percent, along with significant increases in productivity. However, no technology for converting raw woodfuel into forms that can easily be used for cooking without producing smoke and indoor pollution has been found; the smokeless stoves developed mainly for rural areas have had only partial success.

Human resources skilled in both growing wood energy and technology development are available in India, but not in sufficient numbers. Greater focus on awareness and capacity building is required, to promote woodfuel as a renewable energy for climate change mitigation.

The forest carbon stock

Overview of the methodology

The Forest Survey of India (FSI), a government institution, regularly monitors the country's forest resources and estimates the carbon stock of India's forests in all five carbon pools. FSI is working to improve its data on carbon stock, to bring them into line with IPCC's Tier 2 approach, following good practice guidance for LULUCF and using country-specific data. As part of this, in August 2008, FSI commenced a nationwide study to fill the gaps in its forest biomass information, using the following methodology and inputs:

- → forest cover data from 2005 and forest type area, analysed by remote sensing and GIS;
- → growing stock data from the national forest inventory for 2002 to 2008;
- → soil organic carbon data from the national forest inventory;
- → analysis of biomass data on small wood, branch wood, deadwood, litter, shrubs, herbs and foliage from a 2008/2009 study (FSI, 2008b);
- → IPCC default values for below-ground biomass.

Most of the inputs used for estimating forest carbon stock were generated by FSI, apart from the specific gravity for determining biomass and the factors for converting biomass into carbon, which were taken from research published by the Forest Research Institute, the Indian Council of Forestry Research and Education and other research institutes, in addition to IPCC default values.

Since 1987, FSI has been assessing India's forest cover on a two-year cycle, using remote sensing technology. Since 2001, satellite imagery of 23.5 m resolution is digitally interpreted on a scale of 1:50 000. Assessments classify canopy densities into three classes: very dense forests, of more than 70 percent density; moderately dense forests, of 40 to 70 percent density; and open forests, of 10 to 40 percent density. Changes are analysed using the results of the previous cycle, to identify areas that have shifted from one class to another or from forest to non-forest. Forest cover in 2005 was assessed at 67.71 million hectares (FSI, 2008a). Then, by overlying the layer of forest types over that of forest cover, the country was divided into 33 homogeneous strata (each of a specific type and density).

FSI has also conducted national forest inventories since 2002, following a systematic stratified sampling approach based on 3 500 sample forest plots a year, each of 0.1 ha, distributed throughout the country, and on measurements of trees (of more than 10 cm diameter only) and forest floor. A total of about 22 000 plots were laid out between 2002 and 2008. Data are analysed using volume equations developed for different tree species to estimate the growing stock (woody volume of trees) of forest (FSI, 1996), which is estimated at 5 129 million cubic metres.

The national forest inventory collects soil samples for analysing soil organic carbon, but not measurements of total tree biomass (of trees under 10 cm in diameter, and of branch wood), herbs, shrubs, climbers and deadwood. A separate nationwide exercise was undertaken for this purpose in

August 2008, when 1 400 sample plots were established for measuring this biomass and carbon in litter. More than 200 new biomass equations have been developed to estimate the biomass of small wood and branch wood, which is estimated at 1 004 million tonnes. Total biomass of foliage, herbs, shrubs and climbers is estimated at 103 million tonnes, and of deadwood at 56 million tonnes (FSI, 2009a).

Forest carbon stocks

IPCC default values for estimating below-ground biomass are available for different forest types as percentages/ratios of above-ground biomass. These default values range from 0.22 to 0.42. Based on partial analysis of the data, carbon stock is estimated at 6 897 million tonnes, of which about 58 percent is soil organic carbon and 2 800 million tonnes is in live biomass, including 671 million tonnes in below-ground biomass (FSI, 2009a). No separate estimate has been made of carbon emissions from the burning of fuelwood and charcoal; this would require the break-down of fuelwood data into logs and twigs/branches and species composition. Natarajan (1995) found that fuelwood logs and twigs were in a ratio of 1:1 during 1992. Thus, of the estimated fuelwood consumption of 261 million cubic metres, about 50 percent can be assumed to be twigs and the rest logs. The equivalent estimate for biomass is 190[6] million tonnes. Converting biomass into carbon, according to the IPCC default values of 0.43 for twigs/small wood and 0.47 for fuelwood/logs, fuelwood burning in India generates an estimated 85.73 million tonnes of CO_2 emissions and burning charcoal an estimated 0.89 million tonnes, resulting in total estimated CO_2 emissions of 86.6 million tonnes from woodfuel use in 2005.

National carbon substitution policy

India faces the challenge of sustaining its rapid economic growth, in which increased per capita energy consumption will have a direct role, while energy use is contributing directly to the global threat of climate change due to GHG emissions. It must therefore strike a balance between these two contradictory needs. Although India is not required to contain its GHG emissions, as a signatory to UNFCCC and having acceded to the Kyoto Protocol, it is very active in CDM, launching a National Action Plan on Climate Change in 2008. The scope and scale of the new and renewable energy programmes already being implemented have been enhanced, but India also needs to tackle national-level programmes, some of which will directly reduce carbon emissions (PMO, 2008).

The first of these national programmes is the Solar Programme, aimed at significantly increasing the share of solar energy in the total energy mix, while recognizing the need to expand the scope of other renewable and non-fossil options, such as nuclear, wind and biomass. India is a tropical country, where sunshine is available for long hours each day and in great intensity. Solar energy therefore has great potential as a future energy source. It also allows the decentralized distribution of energy, thereby empowering people at the grassroots level. Photovoltaic cells are becoming cheaper, and new, reflector-based technologies will enable the establishment of megawatt-scale solar power plants across the country. The Solar Programme will also launch a major research and development programme, drawing on international cooperation, to enable the creation of more affordable and convenient solar power systems and to promote innovations that enable the storage of solar power for sustained, long-term use.

The second important programme is the Enhanced Energy Efficiency Programme. The Energy Conservation Act of 2001 provides the legal mandate for implementing energy efficiency measures through the institutional mechanism of the Bureau of Energy Efficiency in the central government and designated agencies in each state. A number of schemes and programmes have been initiated, and these are expected to result in savings of 10 000 MW by the end of the eleventh Five-Year Plan in 2012. To enhance energy efficiency, four new initiatives will be put in place:

- → a market-based mechanism to enhance the cost-effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that can be traded;

[6] A weighted density of 0.73 is used to convert fuelwood volume into biomass, based on the density of dominant species.

- → accelerating the shift to energy-efficient appliances in designated sectors, through innovative measures to make products more affordable;
- → mechanisms for financing demand-side management programmes in all sectors by capturing future energy savings;
- → fiscal instruments for promoting energy efficiency.

The third national programme is the Sustainable Habitats Programme, based on improving energy efficiency in buildings, managing solid waste, and switching to alternative modes of public transport. This programme will promote energy efficiency as an integral component of urban planning and urban renewal through the following three initiatives:

- → Application of the Energy Conservation Building Code, which addresses the design of new commercial buildings to optimize their energy demand, will be extended, and incentives provided for retooling existing building stock.
- → Recycling and urban waste management will be a major component of ecologically sustainable economic development. A special area of focus will be the development of technology for producing power from waste, as well as a major research and development programme on biochemical conversion, wastewater use, sewage utilization and recycling options.
- → Better urban planning and a shift to other modes of public transport are principal options for reducing energy use in urban areas. Long-term transport plans will facilitate the growth of medium-sized and small cities in ways that ensure efficient and convenient public transport.

The fourth national programme is the Green India Programme, aimed at enhancing ecosystem services, including carbon sinks. The Green India Programme will be implemented on degraded forest land through direct action by communities, organized through joint forest management committees and guided by state governments' departments of forest. An initial budget of more than Rs 60 billion has been earmarked for this programme, through the Compensatory Afforestation Management and Planning Authority. The programme will then be scaled up to cover all remaining degraded forest land. The institutional arrangements allow the initial budget to be used to leverage more funds for scaling up activities.

Even before launching its action plan on climate change, India was promoting new and renewable energy in response to the growing threat of climate change. In addition to solar power, other important programmes are harnessing wind energy and biomass-based power. During the tenth Five-Year Plan, wind power capacity increased threefold, with the addition of 5 415 MW, and the eleventh plan envisages the addition of another 10 500 MW. The potential for offshore wind energy is estimated at 65 000 MW with a 20 percent load factor. Biomass-based power generation is to be enhanced to about 3 200 MW, by adding 2 100 MW during the eleventh plan. There is no specific focus on enhancing woodfuel resources. In the household sector, the emphasis is on increasing the supply of clean cooking fuel for rural households, to address social aspects associated with the use of traditional fuels, particularly women's health and enterprises. However, the Integrated Energy Policy (2006) recommends encouraging cooperatives to grow tree plantations in villages. Vacant government lands should be given to cooperatives on a long-term basis for these plantations, which women should be encouraged to set up and manage, with financial support.

Hydroelectricity and nuclear power are other environment-friendly energy sources, and India's current energy policy focuses on exploiting these to optimum levels to meet energy requirements. The country's hydroelectric resources are estimated at 84 000 MW at a 60 percent load factor, and 150 000 MW at lower load factors (Planning Commission of India, 2006). India is poorly endowed with uranium, and the available supply can fuel only 10 000 MW. The use of fast-breeder reactor technology will enable these indigenous uranium resources to supply 20 000 MW of nuclear power.

Substitution of fossil fuel with woodfuel and impact on forests and forest industries

The collection of fuelwood from forests is viewed as a major cause of forest degradation in India. The age-old practice for people living in and around forests to collect fuelwood not only to meet their household energy needs but also to generate income continues to this day. The production of woodfuel by raising trees outside forests is one of India's key efforts to reduce pressure on forests and check their degradation.

Sustainable forest management

Although scientific forestry is well established in India, it has remained production-oriented. Some basic changes in perception were brought by the National Forest Policy of 1952, which gave some attention to maintaining ecological balance, along with meeting stakeholders' needs. However, attaining sustainable yields remained the main focus of forest management. A paradigm shift in forest management came with the 1988 National Forest Policy, which foresaw meeting the requirements for fuelwood, fodder, non-wood forest products and small-scale timber production for forest dwellers and local rural populations as the main economic benefit. The generation of direct economic benefits from forests was subordinated to environmental stability and ecological balance.

There is, however, an urgent need to monitor and ensure proper implementation of these policy implications. A quantifiable approach to monitoring and implementing the objectives of sustainability, based on set criteria and indicators, is essential. India has developed a set of criteria and indicators for its specific forestry conditions, based on international processes and national technical consultations and field testing. Eight criteria and 51 indicators specific to Indian forestry conditions have been developed by the Indian Institute of Forest Management in Bhopal. The applicability of sustainable forest management indicators depends on the specific forestry conditions (Rawat *et al.,* 2008). To institutionalize the application of criteria and indicators, the central government has included them in the National Working Plan Code (2004). Some of the working plans recently prepared by forest divisions already incorporate criteria and indicators for monitoring and evaluating sustainable forest management, and many others are working to do so.

Given the current forest policy and focus on sustainable forest management, excessive dependence on forests for woodfuel production is not feasible in India. The current estimated fuelwood production of 52 million tonnes from forests could be slightly increased by improving the stocking levels of degraded forests. India introduced joint forest management, based on the principle of people's involvement, in 1990, and about 22 million hectares of forest land – most of which is degraded, at less than 40 percent density – has been brought under joint management (Ministry of Environment and Forests, 2007). As well as improving the economic status of people living on forest fringes, joint forest management helps to improve the forest stock. The additional woodfuel produced by improved stocking is utilized by local communities. In addition, 15.6 million hectares of forests have been brought into the protected area network of national parks and wildlife sanctuaries, where even fuelwood removal is not permitted by law. Other forest areas on high hills, in remote places and far from human habitation are also excluded from woodfuel uses, owing to accessibility problems.

For climate change mitigation, one of India's main goals is to enhance the carbon stock of forests through improved management and conservation. The reduction of growing stock through the removal of fuelwood defeats this policy goal.

Sustainability of trees outside forests

Most trees outside forests in India do not fall under the public forestry administration and management regime and are in the private sector. There is no national or state-level policy for promoting trees outside forests. Developments in this sector are demand-driven, and there is scope for expansion. About 25 percent of India's woody growing stock, or 1 620 million cubic metres, comes from trees outside forests (FSI, 2008b), which are estimated to produce about 80 percent of industrial roundwood and 75 percent of woodfuel (FSI, 2009b).

As a densely populated country, holdings of cultivable land in India are very small. About 60 percent of households have only marginal landholdings (less than 1 ha), averaging 0.39 ha; about 19 percent have medium-sized landholdings (1 to 2 ha); and the remaining 21 percent have more than 2 ha. Small and medium-sized landholders control 33 percent, and large landholders 67 percent of the land. Only medium-sized and large landholders have the potential for expanding woodfuel resources. Under the Green India Programme, the country's forest and tree cover has to be raised to 33 percent of the geographical area, or to about 100 million hectares from the existing 78.2 million hectares (69 million hectares of forests plus 9.2 million hectares of tree cover). Most of the additional area will have to come from the private sector. The recommended approach includes mass production of high-quality planting materials and the establishment of hi-tech nurseries throughout the country. This would enhance not only the production of woodfuel as a partial substitute for fossil fuels in mitigating climate change, but also the supply of industrial timber for meeting the population's increased needs.

Cost-effectiveness of woodfuel versus fossil fuel

A major factor supporting the substitution of fossil fuel with woodfuel is the lower cost of producing energy from woodfuel. However, comparing the cost-effectiveness of woodfuel with that of fossil fuel on the basis of only the direct costs of purchase and fuel efficiency may not be justified, because of the social cost attached to woodfuel, which can sometimes be collected at no economic cost, and the subsidizing of fossil fuel sales to consumers. Few available studies have compared the costs of these two alternatives.

The Government of India subsidizes the use of fossil fuel for domestic energy for two main reasons: to control forest degradation; and to save women from the drudgery of fuelwood collection. The subsidy is 50 percent. The subsidized retail price of a 14.2 kg cylinder of LPG, sufficient for a household's cooking needs for one month, is Rs 297.00 (US$6.0), or Rs 34 per kilogram, whereas the international import price is about US$10.0 per cylinder. Using fuelwood, the cost of cooking for one household comes to Rs 117.00[7] (US$2.4) per month. Based on energy conversion and calorific value, TERI estimates that 1 kg of LPG is equivalent to 4 kg of fuelwood, and 1 kg of diesel is equivalent to 3 kg (Personal communication). These rough comparisons indicate that fuelwood is a relatively cheap substitute for fossil fuel, but a comprehensive study is needed on the conversion of woodfuel into other convenient forms of energy (electrical, etc.).

Conclusions and recommendations

Renewable energy, including solar, wind and hydro, can make very important contributions to mitigating climate change in India. India's Integrated Energy Policy focuses on these three sources, but there is also scope for enhancing woodfuel resources for the partial substitution of fossil fuel with a carbon-neutral source of energy, especially in rural areas, which have the potential for growing tree biomass. Under the Green India Programme, the Planning Commission calculates that Rs 48 billion (US$1.0 billion) a year will be needed for raising tree plantations, plus additional costs for converting woodfuel into convenient forms of energy. To achieve this, existing policies need to be reoriented and the following activities implemented:

- → The land laws should be relaxed, particularly in dry areas that cannot support agriculture, so that economically viable large-scale plantations owned by individuals or biomass energy-based companies can be established.
- → Proper mechanisms should be developed for controlling the quality of planting materials supplied to farmers through public and private agencies, to ensure high productivity and disease-free planting material.Laws and procedures related to the cutting, transportation and sale of privately owned trees should be simplified. As government forest exists in the vast majority of administrative areas, and the risk of illegal tree cutting and timber theft is negligible, these restrictions should be abolished.
- → The government should fix support prices for woodfuel and develop proper market mechanisms so that woodfuel growers receive remunerative prices.
- → Effective extension mechanisms should be developed through the establishment of model plantations, frequent technology promotion campaigns, and the distribution of attractive extension literature and media publicity, to support farmers and other landholders interested in growing energy plantations or multipurpose trees.
- → There is need for more research into converting woodfuel into user-friendly energy, including through the development of smokeless stoves.
- → Incentives are needed to promote woodfuel-linked biomass gasifiers through greater participation from private players. At present, the Ministry of New and Renewable Resources provides Rs 150 000 (US$3 200) for a 50 kW biomass gasifier plant, and provides

[7] Fuelwood consumption in rural areas is 17.7 kg per capita, or 97 kg per household. The average market price of fuelwood is Rs 1.2 per kilogram (NSSO, 2007).

collection, processing, storage and operation and maintenance services for five years after the guarantee period.

→ It is essential to build the capacity of human resource in the production of woodfuel from high-yielding energy plantations and fast-growing multipurpose trees, and in the development of technology for converting woodfuel into user-friendly forms.

→ The major challenge to promoting renewable energies is that they should have lower production costs than other forms of fuel, so that they can compete nationally and internationally. An essential condition for this is increased productivity from energy plantations through technological inputs. This will also ensure increased removal of carbon from the atmosphere in standing biomass.

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4. Woodfuel development and climate change mitigation in Mexico

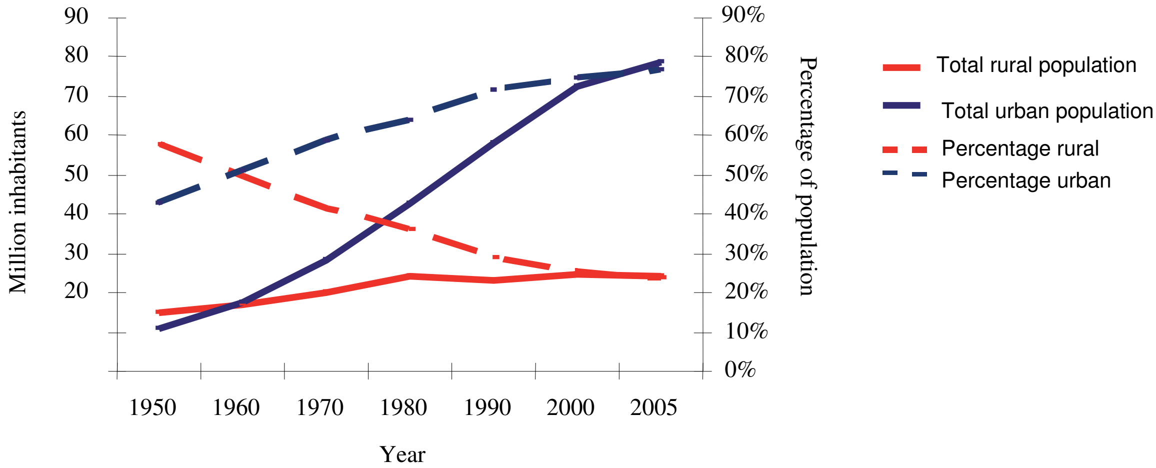
Teresita Arias, Enrique Riegelhaupt, René Martínez Bravo, and Omar Masera Cerutti

Introduction

Country description

Population: Mexico's population in 2008 was 106.7 million people (CONAPO, 2009). In 2005, 23.6 percent of the total population lived in rural and 76.4 percent in urban areas.[8] The urban population increased significantly over the 55 years from 1950 to 2005, growing from 11 million to 79 million people, while the rural population grew more slowly, from 15 million to 24 million; total rural population has remained stable since 1980 (Figure 3.1). This is owing to Mexican government policies for promoting urban and industrial development, while providing little support to the primary production sector, leading to migration from rural to urban areas and to the United States of America. The most highly urbanized regions[9] are Northeast, East-centre, Northwest, North and West-centre (Figure 3.2; Gutiérrez and González, 2004).

Figure 3.1: Rural and urban population in Mexico, 1950 to 2005



Source: INEGI, 2009a.

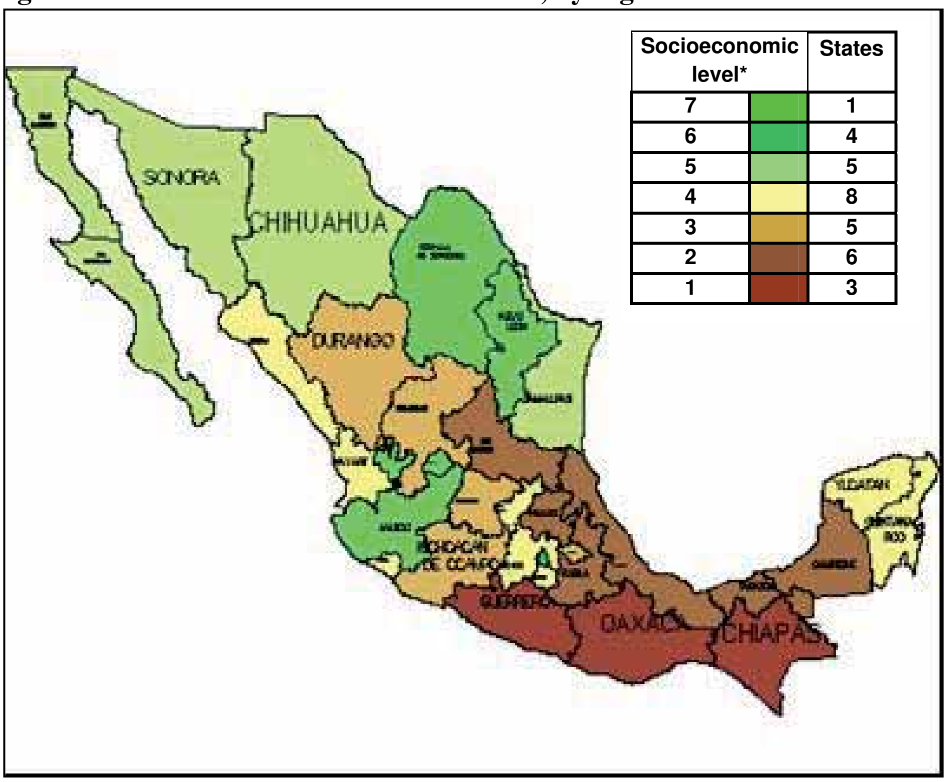
According to the National Institute of Statistics, Geography and Informatics (INEGI), Mexico can be divided into seven socio-economic regions.[10] Mexico City has the highest levels of development and population concentration, followed by Northeast and parts of West-centre regions, where the second and third largest cities (Monterrey and Guadalajara) are located. Southern, Eastern and part of the Yucatan Peninsula are of lower socio-economic status (Figure 3.3; INEGI, 2009b). There is high correlation between INEGI socio-economic status and degree of urbanization, as shown in Figure 3.2.

[8] According to INEGI, settlements with fewer than 2 500 inhabitants are rural, and those with more than 2 500 are urban.
[9] Degree of urbanization is measured by dividing the urban population by the total population.
[10] The main indicators used in INEGI's socio-economic classification are: a) housing infrastructure; b) housing quality; c) population density; d) housing facilities; e) health; f) education; and g) employment.

Figure 3.2: Population and degree of urbanization in Mexico, by region, 2000

Source: INEGI, 2000.

Figure 3.3: Socio-economic status in Mexico, by region



Socioeconomic level*		States
7		1
6		4
5		5
4		8
3		5
2		6
1		3

* Level 1 represents the lowest socio-economic status.
Source: INEGI, 2009b.

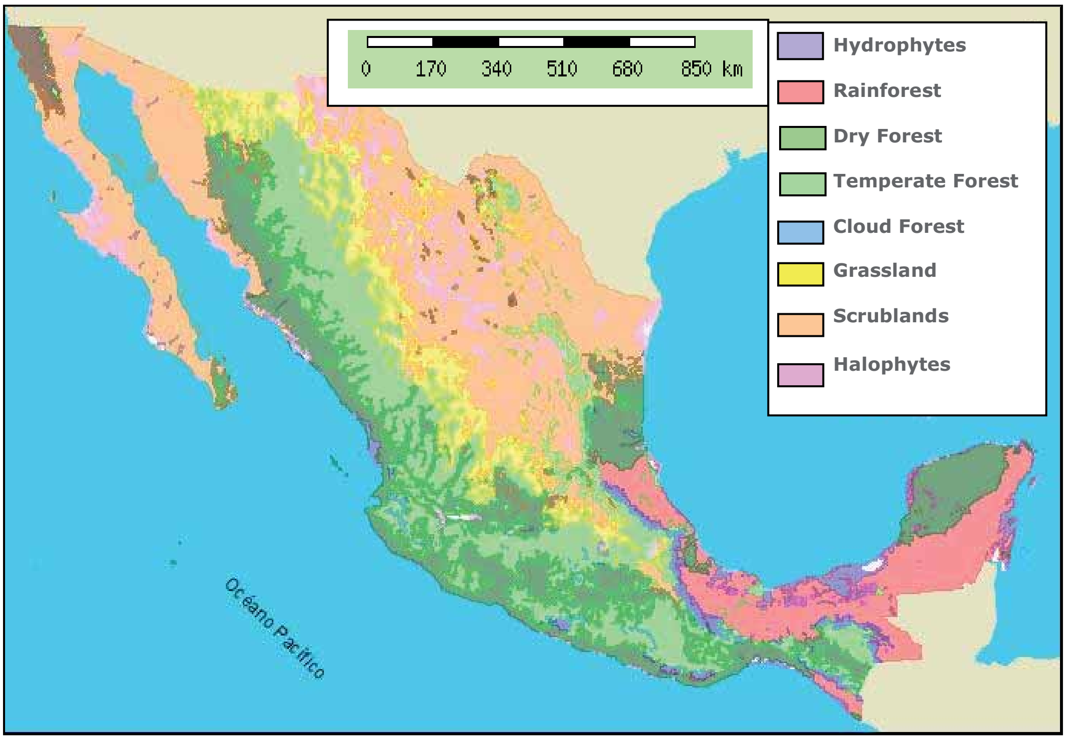
Forest resources: The land area of Mexico is 1 964 375 km^2 (Office of the President of the Republic, 2009). In 2002, the forest area was 1 280 493 km^2, 65.4 percent of total land area, and comprised temperate and tropical forests, followed by scrublands in arid areas (Table 3.1; Ministry of Environment and Natural Resources, 2005). Temperate and cloud forests are composed of mainly conifers and oaks, and are found on the upper reaches of western, eastern, neo-volcanic and southern isolated sierras. Dry tropical forests are found on the lower slopes of these mountains and on the plains of the Pacific and Gulf of Mexico. Rain forests are in the lowlands of eastern and southeastern Mexico. Scrublands are distributed in the north-central highlands and on the plains of Northwest Region (Figure 3:4, INEGI, 2009c). Commercial forest plantations are of little importance in Mexico, but have been established under the government's Commercial Forest Plantations Programme since 1997. The National Forestry Commission (CONAFOR, 2009) reported 39 321 ha of forest plantations in 2005.

Table 3.1: Types and areas of vegetation in Mexico, 2002

Vegetation type	Area (km^2)	% of total land area
Temperate and cloud forests	328 513	16.8
Tropical forests	318 220	16.2
Scrublands	558 103	28.5
Halophytes, hydrophytes and degraded forests	75 657	3.9
Total	**1 280 493**	**65.4**

Source: Ministry of Environment and Natural Resources, 2005.

Figure 3.4: Vegetation cover in Mexico

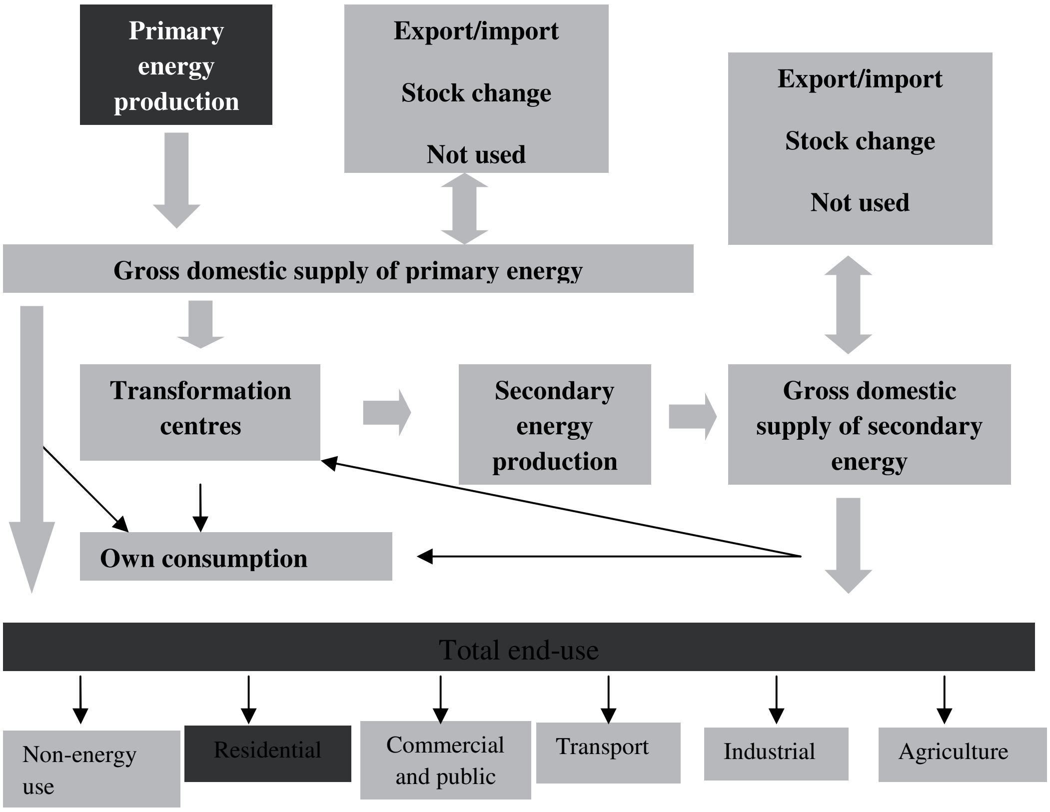


Source: INEGI, 2009c.

Energy supply

The National Energy Balance presents statistical data on sources and end-uses of primary and secondary energy[11] as shown in Figure 3.5. The supply sectors analysed are primary and secondary energy production, and imports of primary and secondary energy.

Figure 3.5: General structure of the National Energy Balance in Mexico, main energy flows
Sectors in black boxes are those with fuelwood participation.



Source: Ministry of Energy, 2009.

Primary energy: Primary energy production in Mexico increased by 8.2 percent between 2000 and 2008. Over this period, annual fossil fuel production increased by 771 petajoules (PJ); natural gas had the largest annual production increase, of 851 PJ, and coal the lowest, of only 3.7 PJ. Annual crude oil production decreased by 98.9 PJ, and natural gas condensates by 39.3 PJ.[12] Total annual production of renewable energy increased by 80.1 PJ, with the greatest growth in annual hydropower production (44.7 PJ) and a slight decrease in fuelwood, of 3.7 PJ. Annual primary electricity production rose by 72.6 PJ (Table 3.2). Although the trend is for reduced production of some fossil fuels and a slight increase in renewable energy, fossil fuels remain the most important source of primary energy, contributing 91 percent of the total.

Secondary energy: Gross annual secondary energy production grew by 649 PJ (13 percent) between 2000 and 2008. Fossil fuels had the highest share in both years, at 82 and 81 percent respectively. Oil products' contribution declined slightly, but remained the largest (at 55 percent), while the contribution from petrol, diesel and fuel oil grew. Major increases were in gasoline, diesel, dry gas and electricity. Annual petroleum coke production had a small absolute increase of 56 PJ, although this represented a 20-fold increase from 2000. Fuel production fell by 22 percent and coking coal by 7 percent (Table 3.3; Ministry of Energy, 2009).

[11] Mexico uses the Latin America Energy Organization (OLADE) methodology for energy balances. The results are comparable with those from the Asia-Pacific Economic Cooperation Council (APEC) and IEA, although the latter uses a different classification of primary and secondary energy sources.
[12] This fall was due to the decline of Cantarell Field.

Table 3.2: Primary energy production in Mexico, by source, 2000 and 2008

	2000		2008	
Source	**PJ/year**	**% total primary energy**	**PJ/year**	**% total primary energy**
Crude oil	6 620	68	6 521	62
Natural gas	1 894	19.5	2 746	26
Hydro*	342	3.5	387	3.7
Fuelwood	250	2.6	246	2.3
Coal	227	2.3	230	2.2
Natural gas condensates	131	1.3	91	0.9
Nuclear*	90	0.9	107	1.0
Sugar cane bagasse	88	0.9	99	0.9
Geothermal*	61	0.6	70	0.7
Eolic*	0.1	0.001	2	0.02
Total	**9 703**	**100**	**10 500**	**100**

* Primary electricity production.
Source: Ministry of Energy, 2009.

Imports: Total imports of energy doubled from 667 PJ in 2000 to 1 331 PJ in 2008 (Table 3.3). Annual imports of primary energy are very low, and concern only coal, which increased by 49 PJ. Secondary energy imports are higher, at 602 PJ in 2000 and 1 217 PJ in 2008, indicating a strong tendency to increase the production of petroleum distillates outside Mexico. Between 2000 and 2008, annual imports of LPG, fuel oil and dry gas declined significantly, while those of gasoline increased by 523 PJ and those of dry gas by 348 PJ.

Table 3.3: Export/import balances of energy products in Mexico

	2000	**2008**
	PJ/year	
Total	**3 193**	**1 955**
Primary energy	**3 795**	**3 172**
Coal	-65	-114
Crude oil	3 860	3 286
Secondary energy	**-602**	**-1 217**
Total coke	-50	-115
LPG	-157	-138
Gasoline	-39	-562
Kerosene	-1	1.7
Diesel	-49	-134
Fuel oil	-224	165
Non-energy products	7	3
Dry gas	-92	-440
Electricity	-3	4

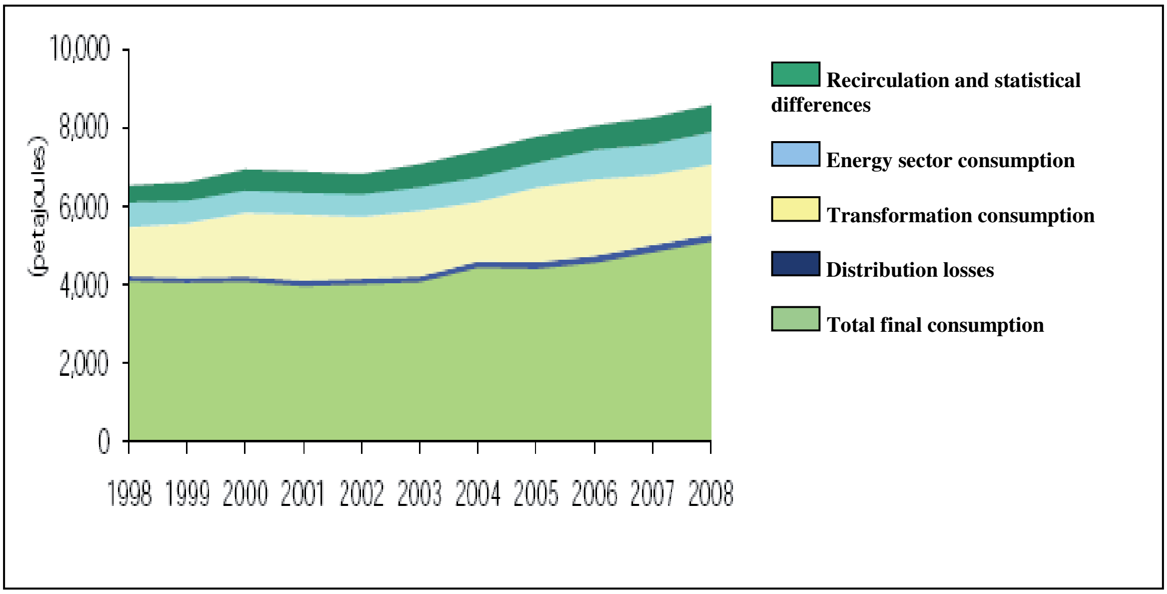
Negative values indicate net imports.
Source: Ministry of Energy, 2009.

Energy demand

The demand sectors discussed in this section are national energy consumption, secondary energy transformation plants, primary and secondary energy exports, and final consumers (Figure 3.5).

National energy consumption: National energy consumption increased by 24 percent between 2000 and 2008, from 6 925 to 8 555 PJ per year. This was owing to an increase of 1 034 PJ in annual total final consumption. The other sectors registered only small increases in consumption (Figure 3.6).

Figure 3.6: Evolution of national energy consumption in Mexico, 1998 to 2008.



Source: Ministry of Energy, 2009.

Demand for transformation plants: The annual primary energy demand of transformation plants increased by 755 PJ from 2000 to 2008. Refineries and topping plants registered the highest increase, of 317 PJ, followed by gas and fractionating plants with 282 PJ, and power plants with 106 PJ. Only coking plants reduced their demand. Refineries and topping plants account for the bulk of total demand (53 percent), especially of crude oil. Gas and fractionating plants require 33 percent, almost exclusively from natural gas. Some 72 percent of power generation uses renewable energy, with hydropower as the largest source. Coal is the second source of energy for power generation (Table 3.4).

Exports: Mexico exports mainly crude oil, both to satisfy demand in other countries and for producing refined fuels that it then imports. Annual exports of crude oil declined by 574 PJ between 2000 and 2008, owing to the decline in stocks in major fields; fuel oil was exported in 2008, having been imported in 2000 (Table 3.3).

End-uses: Annual energy end-use consumption increased by 1 058 PJ from 2000 to 2008. Oil products have the highest demand in end-uses, increasing by a significant 750 PJ. Electricity comes second, and increased by 100 PJ, followed by dry natural gas, which increased by 64 PJ. Coke increased by 125 PJ, while fuelwood decreased by 3.7 PJ (Table 3.5). In order of importance, the main end-use sectors are transport, industry, residential, agriculture, commercial, and public. There were important increases in absolute and relative annual demand in the transport sector (813 PJ), followed by the industrial sector (147 PJ), and the residential sector (55 PJ). The commercial and public sectors had the lowest increase, of only 14 PJ (Table 3.6).

Table 3.4: Primary energy demand for transformation plants in Mexico

	2000		2008	
Use and source	**PJ/year**	**%**	**PJ/year**	**%**
Total	**5 228**	**100**	**5 983**	**100**
Coking	**64**	**1**	**59**	**1**
Coal	64	1	59	1
Refineries and topping	**2 782**	**53**	**3 153**	**53**
Crude oil	2 776	53	3 147	53
Condensed	6	0.1	6	0.1
Gas and fractionating	**1 706**	**33**	**1 988**	**33**
Condensed	125	2	86	1
Natural gas	1 581	30	1 902	32
Power generation	**677**	**13**	**783**	**13**
Coal	183	4	217	4
Nuclear	90	2	107	2
Hydro	342	7	387	6
Geothermal	61	1	70	1
Eolic	0.1	0	3	0

Source: Ministry of Energy, 2009.

Table 3.5: Energy end-uses in Mexico

	2000		2008	
Source	**PJ/year**	**%**	**PJ/year**	**%**
Oil products	2 342	62	3 092	64
Electricity	562	15	662	14
Natural gas, dry	407	11	471	10
Fuelwood	250	7	246	5
Coke	113	3	238	5
Sugar cane bagasse	83	2	97	2
Coal	0	0	8	0.2
Total	**3 757**	**100**	**4 815**	**100**

Source: Ministry of Energy, 2009.

Table 3.6: Energy end-uses in Mexico, by demand sector

	2000		2008	
Sector	**PJ/year**	**%**	**PJ/year**	**%**
Transport	1 615	43	2 427	50
Industry	1 195	32	1 342	28
Residential	695	18	750	16
Agriculture	115	3	145	3
Commercial	116	3	125	3
Public	21	0.6	26	0.5
Total	**3 756**	**100**	**4 815**	**100**

Source: Ministry of Energy, 2009.

Table 3.7: Energy demand in the transport sector in Mexico

	2000		2008	
Source	**PJ/year**	**%**	**PJ/year**	**%**
Gasoline	998	62	1 607	66
Diesel	439	27	639	26
Kerosene	115	7	130	5
LPG	45	3	41	2
Fuel oil	13	0.8	6	0.2
Electricity	4	0.2	40	0.2
Natural gas, dry	0.2	0.0	0.6	0.0
Total	**1 614**	**100**	**2 428**	**100**

Source: Ministry of Energy, 2009.

Table 3.8. Energy demand in the industrial sector in Mexico

	2000		2008	
Source	**PJ/year**	**%**	**PJ/year**	**%**
Natural gas, dry	379	23	431	32
Electricity	336	21	384	29
Total coke	112	7	238	18
Sugar cane bagasse	82	5	97	7
Fuel oil	186	12	84	6
Diesel	55	3	58	4
LPG	42	3	43	3
Coal	0	0	8	1
Kerosene	2	0.1	0	0
Total	**1 194**	**100**	**1 343**	**100**

Source: Ministry of Energy *2009*

The transport sector consumes mainly gasoline and diesel, which had shares of 89 percent in 2000 and 92 percent in 2008. The increase in the consumption sector is due entirely to the increase in annual demand for these fuels, which was 809 PJ (Table 3.7). This significant increase is because transport is the highest and fastest-growing sector in Mexico, whose fleet nearly tripled from 8.3 million vehicles in 1996 to 21.5 million in 2006 (Johnson *et al.,* 2009).

The industrial sector demands mainly natural gas, electricity and coke, which contributed 51 percent of industrial demand in 2000 and 79 percent in 2008. The biggest growth in annual demand was for coke, which increased by 126 PJ for use in steel, cement and mining. Annual natural gas demand grew by 52 PJ, and electricity by 48 PJ, owing to gradual growth in all industries. Fuel oil is the only fuel registering a decrease, of 102 PJ, with significant reductions in the chemical, cement and sugar industries (Table 3.8).

In the residential sector, LPG provides the largest share of demand: 42 percent in 2000 and 40 percent in 2008. Its annual demand grew slightly over the period, by 9 PJ, owing to use in urban areas and a small amount of fuelwood substitution in rural areas. Fuelwood's share was 36 percent in 2000 and 33 percent in

2008, making it the second largest energy source.[13] The slight reduction in fuelwood consumption is owing to its use in rural areas, where population growth is low and there is some replacement of fuelwood by LPG. Electricity registered the largest absolute increase in annual demand, at 41 PJ, owing to growing demand in urban areas and government programmes for rural electrification. Natural gas increased by 10 PJ, because its use has been promoted in some major cities (Table 3.9).

Table 3.9: Energy demand in the residential sector in Mexico

	2000		2008	
Source	**PJ/year**	**%**	**PJ/year**	**%**
LPG	293	42	302	40
Fuelwood	250	36	246	33
Electricity	130	19	171	23
Natural gas, dry	21	3	31	4
Kerosene	1.4	0.2	0.8	0.1
Total	**695**	**100**	**750**	**100**

Source: Ministry of Energy, 2009.

Wood energy consumption and production potential

Overview

The woodfuels addressed in this study are fuelwood, charcoal and forest residues. Consumption of fuelwood and charcoal is considered to be equal to production, as these fuels are not stocked for longer than six months. For forest residues, only production is considered, as their consumption as energy is very low.

The two government agencies in charge of woodfuels are the Ministry of Environment and Natural Resources and the Ministry of Energy. The Ministry of Environment and Natural Resources reports only the production of fuelwood and charcoal, while the Ministry of Energy reports the production and consumption of fuelwood in the residential sector, giving both the same value. Estimates of consumption or production of woodfuels from official sources do not reflect real values. These data are presented in this chapter, but estimates are based on information from case studies, which is considered more reliable. Sources of information are described in the following paragraphs.

Fuelwood: In its National Forest Yearbook (NFY), the Ministry of Environment and Natural Resources (2006) computes the use fuelwood produced in authorized forest logging areas for commercial purposes, which represents only a fraction of extraction. As there is no legal obligation to report fuelwood extracted for households' own consumption, there is no information on this, which is the largest use. In addition, these data have not been updated since the last NFY was published in 2006.

The Ministry of Energy's National Energy Balance includes only fuelwood[14] for direct use in the residential sector in its chapters on primary production and end-use. The National Energy Balance estimates fuelwood consumption, assumed to be equal to production, on the basis of two variables: the number of households using fuelwood according to the population census; and consumption values per household and per region, derived from case studies.

Masera *et al.* (forthcoming) estimated fuelwood consumption in the residential sector for 1990 to 2022 on the basis of census data of the number of households using fuelwood, by municipality, adding a proportion of dual users (fuelwood and LPG) and applying the consumption values for the

[13] Although the National Energy Balance reports fuelwood use in only the residential sector, the need to include small industries and commercial services is recognized.

[14] According to the National Energy Balance, fuelwood includes only energy from forest sources directly used in the residential sector for cooking and heating purposes, and obtained from tree logs and branches, but excluding residues from forest industries (Ministry of Energy, 2009).

specific climatic and ecocultural region. Data on the consumption of fuelwood in the residential sector come from about 20 case studies. This study does not consider commercial consumption.

Charcoal: The Ministry of Environment and Natural Resources' NFY reports statistics for charcoal production based on producers' reports of legally authorized production (from forest permits). The National Energy Balance does not report on wood for charcoal making as a primary source, charcoal as a secondary source, or charcoal end-use.

Masera *et al.* (forthcoming) estimated charcoal consumption and wood used to make charcoal based on saturation and the consumption of charcoal reported in case studies from the cities of Monterrey in Nuevo León State, Victoria, Reynosa and Gonzalez in Tamaulipas State, San Luis Potosí in San Luis Potosí State, Querétaro in Querétaro State, and Villahermosa in Tabasco State (Arias, 2005; 2006; Arias, Miranda and Bacalini, 2006). They report by region, including residential and commercial use, according to INEGI population data for towns of more than 10 000 inhabitants, from 1990 to 2022. This report uses the data in Masera *et al.* (forthcoming) as a best estimate of both fuelwood and charcoal consumption. In comparisons of the three sources of information – NFY, the National Energy Balance and Masera *et al.* (forthcoming) – data from 2005 are used.

Forest residues: Forest logging residue production is assessed on the basis of official statistics (NFY), applying specific factors for each product and group of species.[15]

Woodfuel consumption projections: Projections of fuelwood and charcoal consumption for 2009 to 2020 are taken from Masera *et al.* (forthcoming), assuming that the saturation and specific woodfuel consumptions will remain those of 2005 and applying these to the population growth data reported by CONAPO (2009), by region and municipality size (for fuelwood) or town (for charcoal).

Woodfuel production potential: Estimation of the long-term potential for woodfuel production is based on Ghilardi, Guerrero and Riegelhaupt (2009), and was derived from calculations based on Geographic Information System (GIS) data. Forest areas for seven forest types (three temperate, three tropical and one subtropical scrub; INEGI, 2007) were classified and overlapped on a digital elevation model, a digital roadmap, and a current land-use map, to eliminate areas with slopes of more than 30 percent, areas more than 3 km from roads, and protected natural areas. Forests of less than 25 ha were also excluded. Data on the mean annual increment (MAI) or total tree growth for each forest type were obtained from the National Forest Inventory (2004) and literature reviews, and used to calculate total biomass production by multiplying volumetric increment by mean wood density. By applying specific energy use coefficients[16] estimated for each forest type, the fraction of total stock with more valuable uses (e.g., timber, pulpwood, poles) was deducted from total growth.

The potential for producing wood for energy given in this study therefore represents only the fraction of forest growth that is physically accessible and has no other or more valuable use for industrial purposes. It is a very conservative estimate of potential production, because it does not account for the many forest areas of less than 25 ha, trees outside forests, fruit trees and orchards, coffee and cocoa plantations, living fences, etc. All of these are believed to be important sources of woodfuels, but little information on their productivity is available, so it is not possible to make long-term production estimates of them.

Estimation of short-term potential is based on official data for authorized log extraction, affected by specific coefficients for the generation of residues during logging and industrial operations. No deduction is made for the current use of these residues for other purposes, such as cordwood, pulp chips and fibreboard, which is quite low (Table 3.10).

[15] Forest logging residue recovery factors range from 0.2 to 0.6, depending on the product and species group. For industry, the recovery factor was taken as 0.4.

[16] Energy use coefficients represent the fraction of total tree biomass that has no valuable use or application for industrial purposes (sawlogs, pulpwood, poles). They range from 0.40 in conifer forests to 0.95 in tropical scrublands. They were calculated as (100 – percentage of merchantable timber in the forest)/100.

Table 3.10: Woodfuel production/consumption in Mexico, by reporting source, 2005

	Ministry of Environment and Natural Resources NFY[1]	Ministry of Energy National Energy Balance [2]	Masera *et al.* [3]
Charcoal: commercial sector	No data	No data	0.21
Charcoal: residential sector	No data	No data	0.44
Total charcoal (million tonnes)	**0.06**	**No data**	**0.65**
Fuelwood equivalent to charcoal (million tonnes of dry matter)	**0.29**	**No data**	**3.19**
Fuelwood (million tonnes of dry matter)	**0.18**	**12.38**	**18.39**
Total woodfuel (million tonnes of dry matter)	**0.47**	**12.38**	**21.58**

Sources: [1]Ministry of Environment and Natural Resources, 2006a; [2]Ministry of Energy, 2009; [3]Masera *et al.,* forthcoming.

Current woodfuel production and consumption

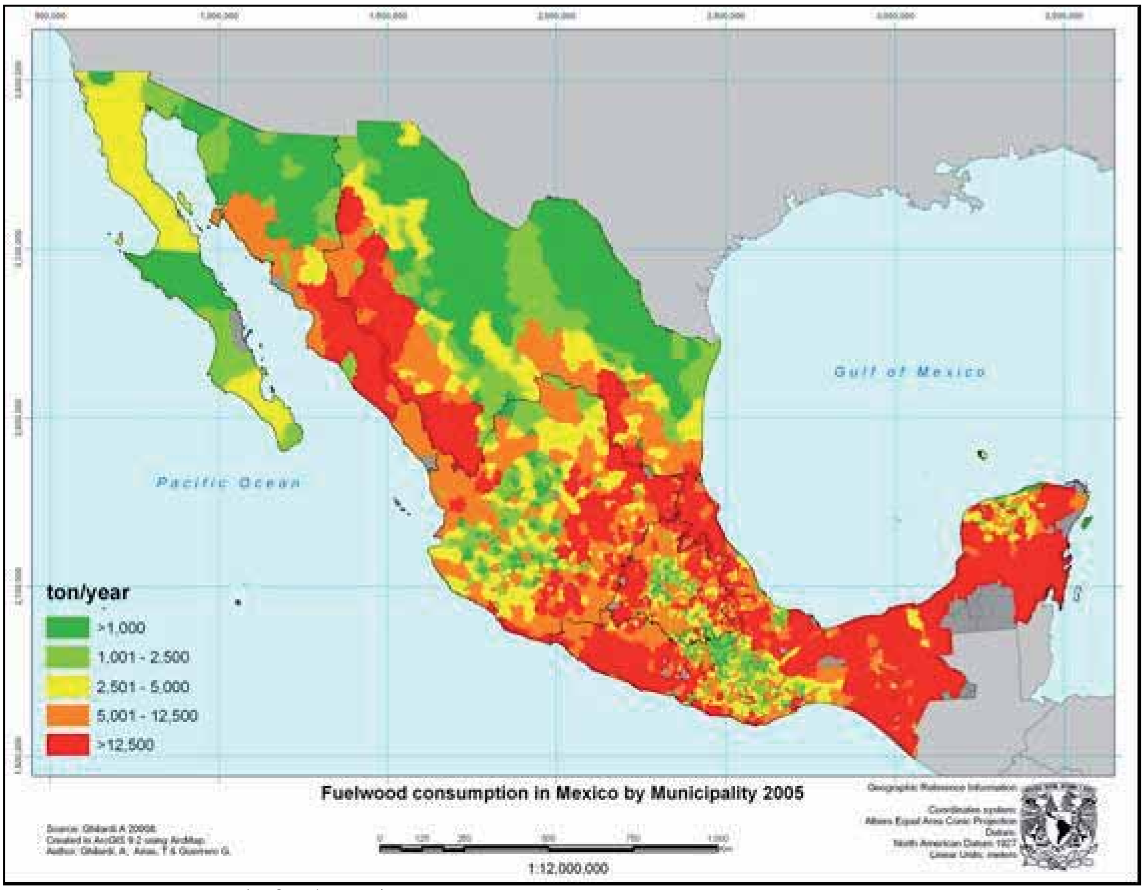
Both fuelwood and charcoal are products of native forests, as there are very few forest plantations in Mexico. Trees outside forests and planted fruit trees (avocado, mango, coffee) also provide substantial amounts of fuelwood. Shifting cultivation systems provide most fuelwood and wood for charcoal in tropical lowlands. In temperate zones, the main source of fuelwood is the genus *Quercus*, while in tropical zones, broadleaved hardwoods – especially *Leguminosae* – are the main source (Arias, 1993; 2002).

Fuelwood: Fuelwood is consumed mainly in rural households for cooking, and also for heating in cold regions. It is used by food vendors and small industries, such as brick kilns, potters and blacksmiths, but this consumption has not been quantified at the national level. Most dual use of fuelwood and LPG is in small towns and on the outskirts of medium cities, but it also occurs to a lesser extent in rural areas. It is estimated that more than 70 percent of fuelwood is obtained by self-supply, and the rest via trade.

Masera *et al.* (forthcoming) estimate residential fuelwood consumption at 18.4 million tonnes of dry matter for 2005. This is 33 percent higher than that recorded by the Ministry of Energy's National Energy Balance, and 100 percent higher than the production reported by the Ministry of Environment and Natural Resources. The figure in Masera *et al.* is probably the most accurate, although it does not include fuelwood used by small industries and commercial activities, such us bakeries and food processors. Among the woodfuels, fuelwood accounts for 85 percent of consumption (Table 3.10), and is also the most important forest product. Timber production for industry (including sawnwood, pulp and plywood) reported in NFY 2005 was only 3.6 million tonnes of dry matter (Ministry of Environment and Natural Resources, 2006a).

Intensity of fuelwood consumption, expressed as the amount (in tonnes of dry matter) of fuelwood consumed per municipality per year is shown in Figure 3.7. Southern and eastern areas, Yucatan Peninsula and the highlands of northwestern Mexico have the highest fuelwood consumption because these have the most rural municipalities. The northwestern region is more urbanized (Figure 3.2), and its high consumption is due to the combined effect of high rural populations at the municipal level and higher specific consumption. Woodfuel consumption is lower in central, western and northern Mexico, where the population is more urban and the country's four largest cities are found: Mexico City, Guadalajara, Monterrey and Puebla.

Figure 3.7: Fuelwood consumption in Mexico, by municipality



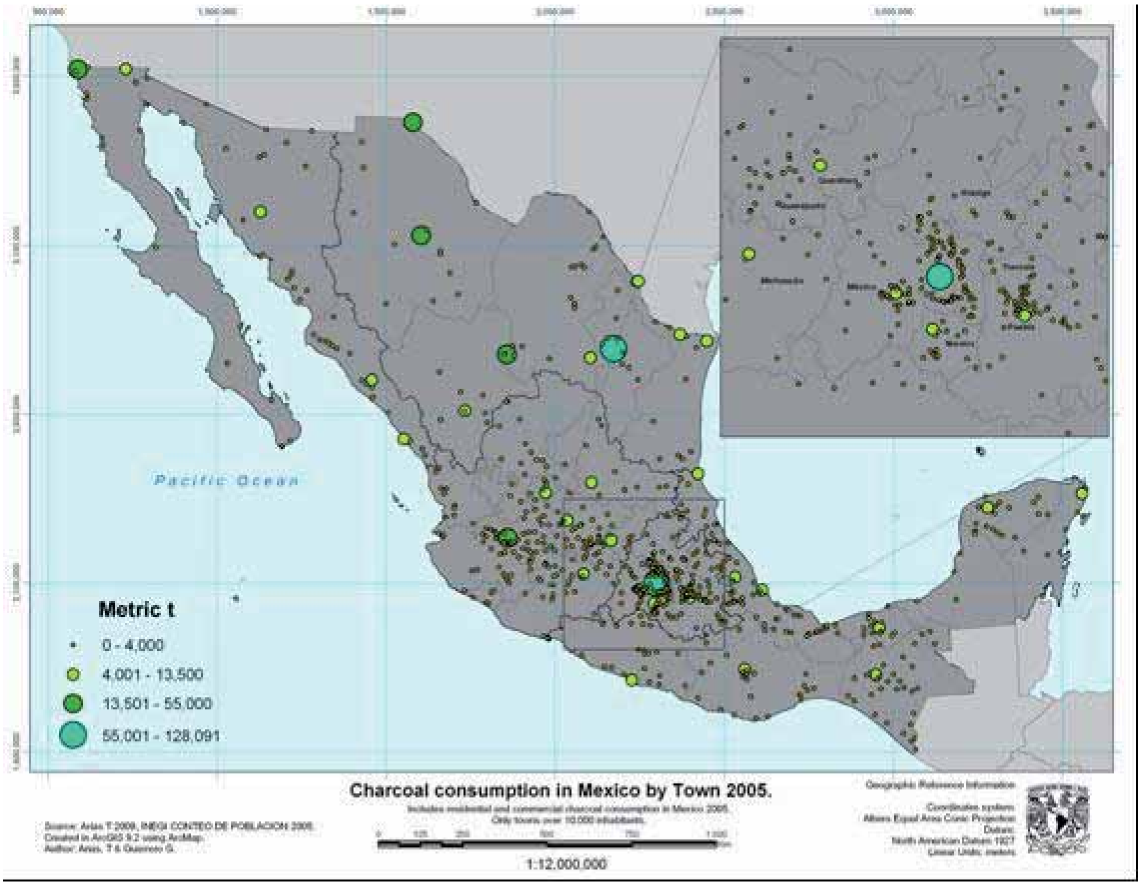
Source: Masera *et al.,* forthcoming.

Charcoal: In Mexico, charcoal is produced in rural areas and almost exclusively consumed in urban ones, so charcoal production is usually for commercial purposes. Charcoal is not used for cooking everyday food, but occasionally special foods (roast beef, roast fish, tamales, etc.). The sectors using charcoal for cooking are the residential and commercial, with 68 and 32 percent of total consumption, respectively (Table 3.10). Very little is used by small industries, and this use has not been quantified.

Masera *et al.* (forthcoming) estimate total charcoal consumption at 0.65 million tonnes in 2005, equivalent to 3.19 million tonnes of wood dry matter. The difference between the figures in NFY and Masera *et al.* suggests that a high proportion of charcoal output (91 percent) is not reported to the forest authorities (Table 3.10). Charcoal is an important woodfuel, contributing 15 percent of total woodfuel consumption.

The geographical distribution of charcoal consumption reflects the number of consumers, all of whom are in urban areas (Figure 3.8). Areas of high charcoal consumption therefore correspond to major urban agglomerations. Urban areas in northern Mexico have particularly high consumption owing to local cooking habits (consumption of roast beef). The highest consumption is in the metropolitan area of Mexico City, which has more than 20 million inhabitants, and in Monterrey, with 3.2 million inhabitants. Six other metropolitan areas have high charcoal consumption; Guadalajara, with 3.7 million inhabitants; Tijuana, with 1.3 million; Ciudad Juarez, with 1.3 million; Torreon and Gomez Palacio, with 0.8 million each; and Chihuahua with 0.7 million.

Figure 3.8: Charcoal consumption in Mexico, urban areas



Source: Masera *et al.,* forthcoming.

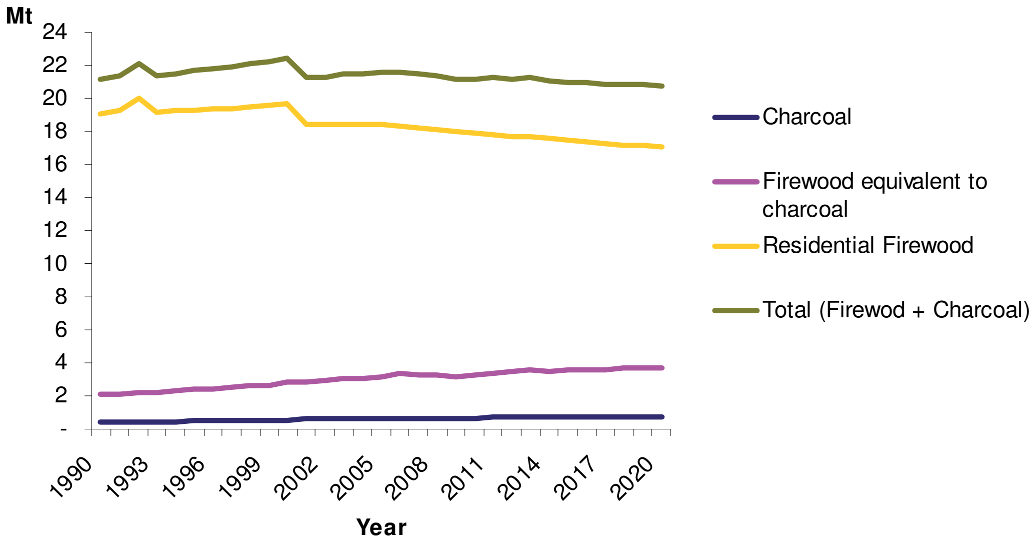
Forest residue production: Forest residue production is very low, at 1.74 million tonnes of dry matter, because Mexico produces little industrial wood (Table 3.11). No data are available on the use of forest residues for energy, which is probably very low, as few sawmills have driers, boilers or other waste recovery facilities.

Table 3.11: Forest residue production in Mexico, 2005

Residue	**Production (million tonnes of dry matter)**
Logging residues	0.86
Industrial forest residues	0.88
Total residues	**1.74**

Source: Estimated from Ministry of Environment and Natural Resources, 2006a.

Figure 3.9: Trends in fuelwood and charcoal use in Mexico, 1990 to 2020



Source. Masera *et al.,* forthcoming.

Woodfuel consumption projections

Historic and projected trends for fuelwood consumption are the opposite to those for charcoal consumption. Fuelwood use showed a slight decrease between 1990 and 2008, and a similar projection is made until 2020, while charcoal consumption grew steadily in the same period, and is expected to keep growing at the same rate (Figure 3.9). This is mainly the result of different growth rates between the rural population, which is stable, and the urban population, which is growing – fuelwood is consumed in rural areas and charcoal in urban.

The growth rate in charcoal consumption is lower than that for urban population (0.8 percent per year), because charcoal consumption varies more from area to area that fuelwood consumption does,[17] and charcoal is used more sporadically. In addition, rural households are increasingly adopting dual use of fuelwood and LPG, thereby reducing their consumption of fuelwood. Total woodfuel consumption is expected to register little change over the next 11 years.

Potential woodfuel production

Of total accessible forest areas, 7 million hectares are temperate (hardwoods and softwoods), 16 million hectares are tropical, and 27 million hectares are shrubland, with approximate area ratios of 1:2:3 (Ghilardi, Guerrero and Riegelhaupt, 2009). However, more than half of total woodfuel potential is projected to come from tropical forests in the humid and sub-humid lowlands, mostly on the Yucatan Peninsula (Table 3.12, Figure 3.10). This is owing to the high mean annual increment (MAI) of these forests and to their high energy use coefficient (80 percent, because of the small number of commercial species and the low ratio of merchantable logs to total tree stock).

About one-third of projected potential comes from temperate forests, owing to the low energy use coefficient (40 percent). Only one-tenth of the projected potential comes from shrubs, owing to their low MAI, which arises from the low rainfall and poor soil conditions in areas of shrubland prevalence. The harvesting of wood for energy does not adversely affect the growth rate of healthy and dominant trees of merchantable species, as woodfuels are obtained from defective, ill or undersized trees, thinning, and species without current value as commercial timber.

[17] The specific consumption of fuelwood is approximately 2.7 tonnes of dry matter per household per year; that of charcoal ranges from 0.15 to 0.39 tonnes of fuelwood equivalent.

Table 3.12: Potential sustainable production of wood for energy in Mexico

Forest type	MAI	*Confidence interval*	MAI	*Confidence interval*
	(million tonnes of dry matter/year)		PJ/year	
Temperate softwood	7.1	*2.1*	142	*42*
Temperate hardwood	13.7	*4.8*	274	*96*
Tropical (low, mid, high)	31.6	*9.9*	632	*198*
Shrubs	6.5	*2.6*	130	*52*
Long-term[1]	**58.9**	***11.5***	**1178**	***230***
Short-term[2]	**1.7**	**n.a.**	**35**	**n.a**

[1] Potentially available as by-product of sustainable management of all accessible areas.
[2] Immediately available as residues of current harvest and processing, at 2008 levels.
Source: Ghilardi, Guerrero and Riegelhaupt, 2009.

Figure 3.10: Wood available for energy from natural forests in Mexico

Source: Ghilardi, Guerrero and Riegelhaupt, 2009.

Comparing long-term potential (58.9 million tonnes of dry matter per year) with present use of fuelwood (20 to 22 million tonnes of dry matter per year), mostly for household consumption, there is an apparent excess of about 38 million tonnes of dry matter per year. However, it must be noted that the National Forest Inventory probably underestimates MAI, as it represents only net growth, disregarding natural stand mortality. Dead and moribund trees are the largest source of the wood collected for household use, and trees outside forests, which are not accounted for in this estimation of potential woodfuel production, are another important source of fuelwood for rural households. It may be realistic to assume that most of the fuelwood extracted for own consumption in rural households comes from, or replaces, the natural mortality of trees in forests plus the growth of trees outside forests. Thus, most of the long-term potential could be considered as available for future use by other sectors.

As the aggregated residential demand for woodfuels (charcoal and fuelwood) is projected to remain at the level of 20 to 22 million tonnes of dry matter per year until 2025, a conservative estimate of the future availability of wood for energy would be about 37 to 39 million tonnes of dry matter per year in the period 2008 to 2025, while a more probable estimate would be about 55 to 59 million tonnes.

Several barriers to realizing the production potential of woodfuels can be foreseen. The first is the need to change existing management systems and practices, which are based on selective cutting for large-sized logs, and very seldom include thinning, salvation cuts and cleaning cuts. A second barrier is the need to develop a market demanding sizable amounts of woodfuels and paying prices that reflect the substitution value of fossil fuels. A third barrier is the need to change the goals and capacities of government agencies in charge of regulating forest activities, which currently favour low-intensity management. The fourth, but not the least, challenge lies in the current tenure of forest lands, which belong mostly to *ejidos* (cooperatives) and communities with very little capacity to apply intensive management practices and/or very little access to industrial woodfuel markets. Alternative efficient and mature end-use technologies for the utilization of wood for energy in the residential, industrial and power sectors need to be developed, and institutional capacities need to be strengthened. Entrepreneurial capacity is in a very early state of development. Private enterprises that could be interested in woodfuels, such as sugar mills, independent power producers, and iron and cement industries, are not forest owners and are understandably reluctant to invest in new technologies for the use of woodfuels if there are no guarantees of long-term supply.

Wood energy and climate change

Status of and methodologies used in national carbon inventories

Mexico is a Non-Annex I country in the Kyoto Protocol. Its main responsibility towards UNFCCC is therefore to produce periodic National Communications reporting mitigation actions and adaptation strategies. Although Mexico does not have an obligation to include national inventories of GHG emissions in its UNFCCC reporting, the Mexican government has prepared and submitted three inventories since 1997. The Fourth Communication was presented at Fifteenth Conference of the Parties to UNFCCC in Copenhagen in December 2009.

Following UNFCCC recommendations, Mexico has accounted and reported emissions from the six sectors suggested by IPCC. In the land use, land-use change and forestry (LULUCF) sector, as well as in the other five sectors, the report includes the six gases listed in Annex A of the Kyoto Protocol, which are accounted for in accordance with the guidelines and using the specific software developed by IPCC (1996). The guidelines detailed in the IPCC reference manual (IPCC, 1996) describe the methodology for calculating the GHG balance from each source and sector, and provide recommendations for reducing the uncertainty of assessments.

However, Mexico's accounting of emissions from the LULUCF sector under these guidelines has encountered two problems that increase the uncertainty of the results of the three inventories it has prepared:

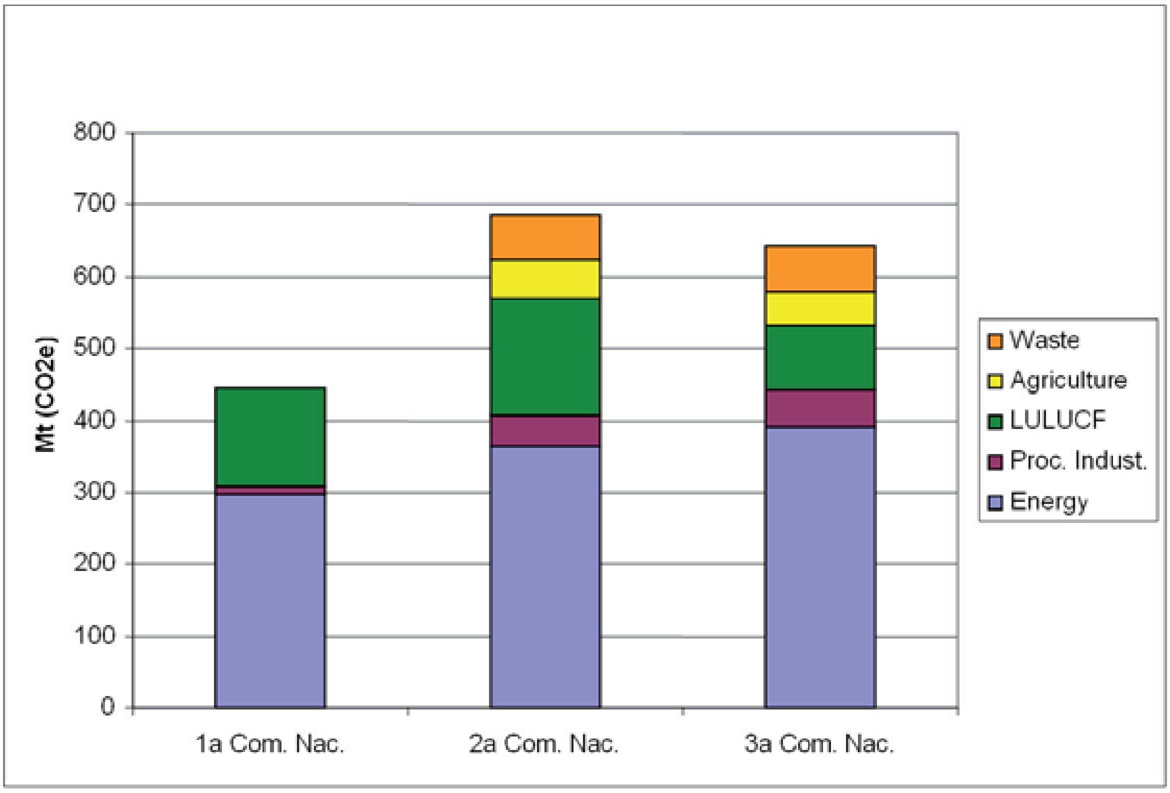
- → The IPCC classification of vegetation does not correspond to the Mexican classification.
- → Mexico has no forest statistics that represent the status of each forest type in a time sequence prior to 1990, as recommended by IPCC methodology.

The lack of such data has made it more difficult to estimate GHG emissions. This problem affected both the first and second inventories of LULUCF emissions, resulting in assessments of the lowest level, Tier 1. The accounting procedure implied the use of many simplifications in the classification of vegetation, generalized parameters for GHG emissions, and the use of default values from international references owing to the lack of national measurements. As a consequence, the estimates in this sector have high levels of uncertainty.

Results of national inventories of GHGs: The First National Communication reported total emissions of 444.4 million tonnes of CO_2 equivalents, of which 31 percent (135.9 million tonnes) corresponded to the LULUCF sector (Ministry of Environment, Natural Resources and Fishery, 1997). This national data use 1990 as the baseline year, according to IPCC recommendations. In the Second National Communication (Ministry of Environment and Natural Resources, 2001), all other sectors' inventories reached Tier 2 for 2000, while LULUCF achieved only Tier 1, and only for the period 1994 to 1996, owing to the lack of updated information on the forest sector, especially on deforestation rates, biomass densities, soil organic carbon content, and woodfuel estimations.

The Second National Communication reported net emissions of 686.1 million tonnes of CO_2 equivalents, of which 161.4 million tonnes were from the LULUCF sector (Ministry of Environment and Natural Resources, 2001). The Third National Communication reported net emissions of 643.3 million tonnes of CO_2 equivalents, of which 89.9 million tonnes were from LULUCF (Ministry of Environment and Natural Resources, 2006, Figure 3.11).

Figure 3.11: GHG emissions (Mt of CO_2 equivalents) reported by National Communications in Mexico



Sources: Ministry of Environment, Natural Resources and Fishery, 1997; Ministry of Environment and Natural Resources, 2001; 2006.

The role of fuelwood consumption in national GHG emissions: GHG emissions arising from fuelwood use are reported on the basis of IPCC methodologies for assessing fuelwood volume harvested from each vegetation type. Under these guidelines, fuelwood consumption is included in the estimation of harvested biomass in the forest management section.

The IPCC methodology requires two types of data: the amount of fuelwood used, and the area from which it is extracted, classified by vegetation type. Because of the lack of official statistics, the first and second National Communications used data from case studies (Diaz, 2000). The third communication used data obtained from application of the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model, which presents fuelwood consumption in a spatially explicit format, and is based on statistics for population, saturation and specific consumption from case studies, processed by GIS software (Masera *et al.,* 2006; Ghilardi *et al.,* 2007; Ghilardi, Guerrero and

Riegelhaupt, 2009). The use of the WISDOM model represents an improvement in the estimation of GHGs from fuelwood use. Charcoal consumption was not included in any of these estimates.

It should also be noted that the methodology proposed by IPCC does not differentiate among emissions from different patterns and devices of woodfuel end-use. This is relevant, as it has been demonstrated that both the device and the fuelwood condition as-burnt greatly affect GHG emission patterns.

Table 3.13 summarizes net emissions from LULUCF, i.e., the balance between gross emissions and carbon sequestration due to forest management and vegetation growth in fallow lands. Emissions from fuelwood consumption are included in the National Communication's section on Forest management.

Table 3.13: Net emissions from LULUCF in Mexico

	million tonnes of CO_2 equivalents	
LULUCF subcategory	**2nd National Communication**	**3rd National Communication**
Biomass, burnt and deferred	110.0	64.5
Soil carbon	89.2	30.3
Forest management	-30.2	4.9
Fallow lands	-11.8	-12.9
Total net emissions	**157.3**	**86.9**

Sources: Ministry of Environment and Natural Resources, 2001; 2006.

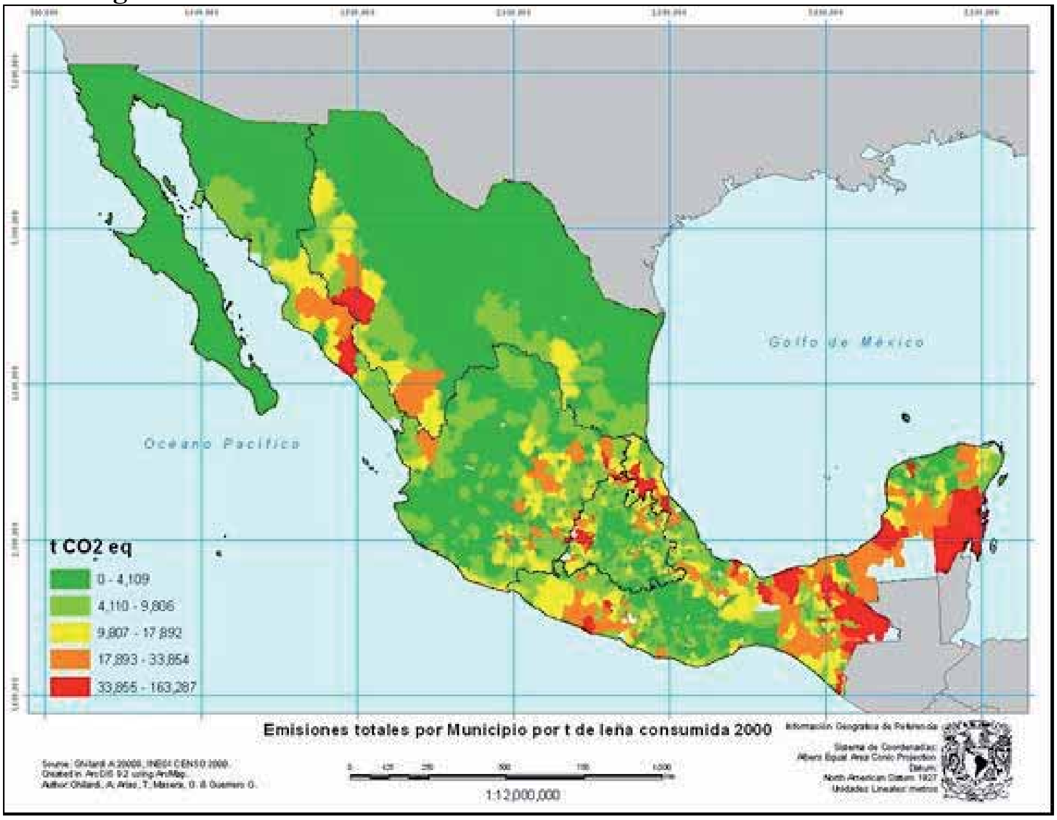
Using the WISDOM model, a detailed balance between woodfuel supply from forest growth and fuelwood consumption was conducted, both at the national level and for each municipality (Figure 3.12). The details of these calculations are fully explained in Ghilardi *et al.,* 2007. From this analysis, it was found that only 9.1 percent of total fuelwood used in Mexico contributes to net CO_2 emissions, corresponding to 3.5 million tonnes of CO_2 equivalents per year, or 4 percent of total emissions from the LULUCF sector.

National carbon substitution policies

Mexico's carbon mitigation policies are integrated into the Special Climate Change Programme (PECC) adopted in 2009 (DOF, 2009). This programme includes all the government actions that may have a sizable impact on carbon mitigation in the 2000 to 2008 period. PECC's overall goals are to reduce GHG emissions to 50 percent of their 2000 levels (i.e, to 340 million tonnes of CO_2 equivalents per year) by 2050 and to promote adaptation to climate change. Achievement of this mitigation goal will require major changes in energy production, consumption and end-use, as well as in land-use patterns.

PECC mitigation goals for 2008 to 2012 (Table 3.14) correspond to four main sectors: forestry, oil and gas extraction, energy efficiency, and power generation. Forestry has the biggest share (20 percent), closely followed by oil and gas extraction (19 percent), with energy efficiency in third place. The main mitigation actions in forestry are promotion of sustainable forest management on 2.95 million hectares; incentives for Reducing Emissions from Deforestation and Forest Degradation (REDD); payments for environmental services, also targeting REDD; establishment of environmental management units and new protected natural areas; development of commercial forest plantations; and efficient rural stoves. These actions aim to curb emissions by avoiding deforestation and reducing domestic woodfuel use, but none of them implies the substitution of other source of energy with woodfuels. PECC stipulates that the forest sector's current role as a source of emissions should be controlled, and that the forest sector should eventually become a net carbon sink, but not a source of renewable energy to be used to mitigate fossil fuel emissions. CONAFOR is responsible for practically all of these actions.

Figure 3.12: Net GHG emissions from fuelwood harvesting in Mexico, by municipality, according to the WISDOM model



Source: Ghilardi *et al.,* 2007. (Municipalities shown in red are those with the greatest emissions.)

Actions in the oil and gas sector include the reinjection of associated natural gas, improved operational efficiency and co-generation by Mexican Petroleum, all to be implemented by the Ministry of Energy. Energy efficiency comprises improved landfills, the introduction of more efficient electric appliances, railroad transportation, efficient buildings, the scrapping of old vehicles, road building, and clean urban transport, to be implemented by various government agencies. Power generation includes a target for the self-supply of renewable generation (3.6 million tonnes of CO_2 equivalents), besides eolic generation, the gasification of oil burning utilities, and new hydropower. Implementation will be through private initiatives and government companies.

Table 3.14: PECC actions and goals, 2008 to 2012

	Mitigation target	
	(Mt CO_2 equivalents)	Share (%)
Sustainable forest management (2.95 million ha)	11.88	6
Incentives for REDD	8.97	5
Efficient rural stoves (600 000 units)	1.62	1
Payment for environmental services (2.175 million ha)	6.27	3
Environmental management units (2.5 million ha)	4.19	2
Protected natural areas (0.75 million ha)	3.36	2
Commercial forest plantations (0.75 million ha)	1.48	1
Sub-total forest sector	*37.77*	*20*
Oil and gas extraction	*36.33*	*19*
Energy efficiency	*23.29*	*12*
Power generation	*4.31*	*2*
Others	*23.68*	*13*
Total	**186.83**	**100**

Source: Based on DOF, 2009.

Potential for woodfuel substitution and emissions reduction

Several interventions for substituting fossil energy with woodfuels in the power, industrial and residential sectors have been analysed in a study by the World Bank (Johnson *et al.,* 2009), along with other interlinked interventions in the forest sector. When assessing the roles of the agriculture and forestry sectors in its low carbon development scenario for Mexico, this study – *Low carbon development for Mexico* – noted the following:

> *...there is great potential for modern bioenergy as an energy source to reduce GHG emissions, as well as to contribute to medium and long term energy diversification…..*
> *The agriculture and forestry sectors have been identified as two of the key areas for reducing GHG emissions in Mexico ... while minimizing possible negative impacts on food production and biodiversity conservation…..*
> *The interventions in this sector that have the highest benefits are those that achieve both (i) the substitution of fossil fuel use via the sustainable production of biomass energy and, (ii) reduced deforestation and forest degradation.*

Analysis of a wide range of possible interventions in the forestry sector identified several that were considered technically and financially feasible, although they face some barriers to implementation (Table 3.15).

Table 3.15: Summary of mitigation options for the forest sector in Mexico

Intervention	Area (million ha)	Mitigation (million tonnes of CO_2 equivalents/year)
Biomass electricity (wood-based)	12.0	17.091
Efficient charcoal production	2.8	11.273
Improved stoves		9.955
Wildlife management	30.0	9.818
Reforestation and restoration	4.5	7.682
Afforestation	1.6	6.955
Forest management	9.0	4.182
Payment for environmental services	5.0	2.318
Fuelwood co-firing	0.1	1.955
Total	**65.0**	**71.227**

Source: Based on Johnson *et al.,* 2009**.**

Power sector: Biomass electricity entails the generation of electricity using fuelwood produced as a by-product of sustainable managed forests. It is assumed that logs (i.e., 30 percent of wood harvest) will be sold for other purposes, while forest thinning and logging residues will be used as fuelwood in woodchip-fired power plants. Up to 200 small power plants (with a capacity of 25 MW each) will be built in regions with native forests, achieving a total installed capacity of 5 000 MW by 2030. To supply woodfuel sustainably, each power plant will need 600 km^2 of well managed forests located in a forest basin of 1 900 km^2, with an average transportation radius of 16 km. Net mitigation over 21 years of operation will be 0.93 million tonnes of CO_2 equivalents[18] per plant, through avoiding coal power generation. This labour-intensive intervention could create approximately 200 000 jobs throughout Mexico. Although there is little experience with this kind of generation technology in Mexico, its use is widespread in other countries, such as the United States of America, Sweden and Austria.

Fuelwood co-firing in coal-fired power plants generates electricity using wood from managed native forests, mixed or alternated with coal. Of the three coal-fired power plants in Mexico, Petacalco Plant (Guerrero State, 2 100 MW) is the only one close to forests that can provide an

[18] Definitions of CO_2 equivalents were taken from IPCC, 2001.

adequate wood supply, so the intervention is limited to this power plant.[19] At a 20 percent substitution level, wood consumption will be about 0.27 million tonnes of dry matter per year, with net mitigation of 43 million tonnes of CO_2 equivalents in 20 years. About 90 000 ha of managed forests will be needed to supply this plant, and it is assumed that these can be found in a 3 000 km^2 basin, with an average transport radius of 21 km.

Industrial sector: About 600 000 tonnnes of charcoal are currently produced each year in Mexico, to meet the needs of the residential and commercial sectors (Masera *et al*., forthcoming). The proposed intervention increases charcoal production 13-fold to meet increasing urban demands and to substitute the coke used in the steel industry. The intervention will also replace existing traditional earthen kilns with more efficient brick kilns. It is assumed that efficient charcoal kilns will supply 70 percent of urban charcoal consumption by 2030, and 75 percent of the pig iron industry demand, currently supplied by imported coke (3.2 million tonnes per year). At this level of substitution, some 2.5 million tonnes of charcoal per year will be needed to address the industrial demand, for which 5 600 production modules of 500 ha each will have to be developed. This will require 2.8 million hectares of forest in a radius of 400 km from the iron plants. Net mitigation will reach 248 million tonnes of CO_2 equivalents in 22 years, assuming continued growth of both industrial and domestic consumption.

Currently, there are no specific government programmes for the implementation of efficient brick charcoal kilns, but the technology and practice are internationally widespread. The substitution of charcoal for coke is also standard practice in the Brazilian pig iron industry. Efficient charcoal making has a threefold impact on emissions reduction:

→ Brick kilns have a higher average conversion rate for fuelwood to charcoal, at 30 percent, than traditional earth-mound kilns, with 18 percent. They therefore require less forest biomass extraction for the same level of production.

→ The specific GHG emission rate from brick kilns is lower than that from earth-mound kilns (2.5 against 3.5 tonnes of CO_2 equivalents per tonne of charcoal).

→ The non-renewability of wood harvesting is assumed to be 0 percent when charcoal is produced in managed forests, compared with 80 percent in the current production system.[20]

Table 3.16: Traditional and improved charcoal kiln assumptions

Kiln assumption	**Traditional kiln**	**Improved Kiln**
Charcoal/wood ratio[1]	18%	30%
Labour days per tonne of production[1]	6.00	2.22
Investment per kiln[1]	Not relevant	US$1 980
Operation and management, first year, per kiln (training and supervision costs) [1]	Not relevant	US$146
Lifetime[1]	Not relevant	5
Emissions of CO_2[2] (tonnes CO_2 per tonne of charcoal	2 403	1 382
Emissions of other gases (CH_4 and N_2O) [2] (tonnes CO_2 per tonne of charcoal	1 106	1 108
Percentage of non-renewability	80%	0%

Sources: Johnson *et al.,* 2009; **[1]** Arias and Riegelhaupt, draft; **[2]** Pennise *et al.,* 2001.

[19] The expansion plan for the electricity sector foresees the establishment of several new coal-fired plants over the next 30 years, many of them in locations where woodfuels are available. Wood co-firing technology may therefore be included from the design phase of these new plants.

[20] The renewability of wood harvest depends on the harvest-to-growth ratio. When the harvest is lower or equal to forest growth, it is assumed that production is fully renewable. In Mexico, most charcoal is currently produced in forests that are cleared for cropping or grazing, and is thus non-renewable.

Residential sector: Biomass consumption accounts for 32.8 percent of residential energy demand and is primarily used by rural households for cooking in traditional open fires. In Mexico, rural households' transition to LPG faces important economic and cultural barriers, and a more feasible way of addressing both health impacts and GHG emissions in the short term is to introduce improved biomass stoves (Troncoso *et al*., 2007).

The replacement of traditional open fires by more efficient devices in rural households reduces fuelwood consumption and improves combustion efficiency, thereby reducing both the net CO_2 emissions linked to the non-renewable fraction of biomass and the non-CO_2 emissions linked to incomplete combustion. The goal stated by PECC (600 000 stoves between 2008 and 2012, or 120 000 stoves per year) means that total replacement of traditional stoves will not be achieved until 2040. With appropriate training, technical assistance and follow-up, this period could be much shortened, achieving large net benefits, including to health and time savings.

The intervention proposed in Johnson *et al.* (2009) envisages constructing and maintaining improved stoves for all households with traditional devices by 2030 (3.9 million improved stoves). At an adoption rate of 60 percent, assuming 50 percent fuelwood savings and reduced emissions – from 2.0 to 1.62 tonnes of CO_2 equivalents per tonne of dry matter – total mitigation will be 22 million tonnes of CO_2 equivalents over 22 years, while fuelwood consumption will fall from 18 million to 12 million tonnes of dry matter per year by 2030.

REDD: Forest management reduces deforestation and forest degradation, diminishing emissions from LULUCF through the sustainable production of woody biomass to be used as timber or for other non-energy purposes. Direct mitigation will be 148 million tonnes of CO_2 equivalents in 22 years. This intervention also has an indirect effect on the production of wood for energy, since logging and industrial woody residues may be used as woodfuels in pulp and paper, sawmill and fibreboard plants or in other sectors.

Wildlife management will involve the scale-up of activities in a current Federal Government programme that provides financial incentives to establish wildlife management units in private and communal lands. It is assumed that the income from wildlife management (mainly in the form of hunting permits) will be used to protect these areas against wood poachers and wildfires, thereby reducing deforestation and forest degradation. Net mitigation from such wildlife management areas is expected to be 316 million tonnes of CO_2 equivalents in 22 years.

Payment for environmental services will expand a current government programme that provides direct cash payments to forest owners in exchange for forest protection. It is assumed that payments will be equal to the opportunity costs of using the land for other purposes, and will enable owners to establish mechanisms for reducing deforestation and degradation. Accumulated mitigation from this proposal will be 51 million tonnes of CO_2 equivalents.

Afforestation and reforestation: Afforestation entails the planting of *Eucalyptus* and *Pinus* species on 1.5 million hectares, for the production of marketable timber for sawn products, cellulose, poles and fuelwood. Mitigation potential is based in the assumption that 50 percent of the carbon content of each harvest is emitted into the atmosphere, and the rest is captured in long-life wood products. Expected accumulated mitigation is 153 million tonnes of CO_2 equivalents.

Reforestation and restoration involve the planting of native species on 4.5 million hectares where native vegetation has been cleared and the soil is degraded or eroded. This does not assume any productive use of forest biomass. Mitigation will depend on the intake and permanent storage of carbon in woody biomass, and is estimated at 169 million tonnes of CO_2 equivalents between 2008 and 2030.

Cost-effectiveness and financial competitiveness of replacing fossil fuels with woodfuels

Johnson *et al.* (2009) defined the cost-effectiveness of replacing fossil fuels with woodfuels as the current value of the net benefit of avoiding emissions of 1 tonne of CO_2 equivalents, in US$ per tonne of CO_2 equivalents. To calculate this value, all the annual emission reductions were added up for each option, and annual net costs were discounted at 10 percent per annum. The cost-effectiveness ratio was then calculated by dividing annual costs by total annual emission reductions.

Net benefit was calculated by subtracting the direct financial costs from the direct benefits, including energy cost savings (i.e., the difference between fossil fuel and woodfuel costs) and other monetary incomes (timber sales, hunting permit sales, etc.). Indirect benefits such as environmental externalities were not quantified. The financial costs reflect the economic opportunity costs, with corrections for taxes and subsidies, and traded goods accounted at their import and export parity values.

The additional organizational and institutional interventions that might be required to overcome the barriers to each option were not included as implementation costs, because these cannot be calculated until the specific interventions have been designed.

The project life of each intervention was based on the economic life of the most important asset. The remaining salvage values of less important assets with longer lives were added back into the cash flow at the end of the project. For assets with shorter lives, which must therefore be replaced during the project, the investment values were entered into the cash flow at more than one point. The time span of the interventions was set at 2008 to 2030.

The positive benefits (or negative costs) of investment options typically imply the presence of non-economic barriers that impede or discourage investors or institutions from following (or avoiding) an action that cost/benefit calculations suggest would make economic sense. The surmountability of barriers, and the cost of interventions for surmounting them make up the third criterion in the rating of investment options. The other two criteria were the net benefit per tonne of GHG reduction, and the potential amount of GHGs that can be reduced by the option.

Table 3.17 shows that the first four interventions, with negative mitigation costs, account for two-thirds of potential cumulated mitigation and use one-fifth of Mexico's forest area. A negative mitigation cost means that the option concerned has a positive cash flow – even after discounting at 10 percent per year – and could be implemented without payments for GHG mitigation. The last five interventions have positive mitigation costs, so would be feasible only if payments for GHG mitigation are equal to or higher than these costs – or, possibly, if the discount rate is less than 10 percent per year. The total investment required for the negative mitigation cost options is US$12.248 billion over 22 years, to mitigate 42.5 million tonnes of CO_2 equivalents per year. However, the first three interventions require US$1.018 billion to mitigate 25.4 million tonnes of CO_2 equivalents per year on only 11.8 million hectares, while the biomass electricity option requires higher up-front investments and has a relatively poor financial performance owing to the high discount rate applied (10 percent) and the low prices paid to independent power producers in Mexico. However, investment in new biomass power plants means that fewer fossil fuel plants will have to be built, so the net investment needed will be roughly half.

The positive mitigation cost options are mostly of the REDD type. As these interventions do not produce or use woodfuels to replace fossil fuels – apart from for wood co-firing in coal power plants – their potential for emission reductions is lower, and depends mainly on their capacity to reduce deforestation and forest degradation. In total, this group of options requires twice as much area to achieve one-third less mitigation than the first group.

Financial analysis shows that there are good opportunities for using woodfuels in the power, industrial and forest sectors, and for efficient energy options in the residential sector, which could realize significant emission reductions. However, a number of barriers to implementation must be surmounted.

Barriers to sustainable forest management: As in most other Latin American countries, Mexico's forest authorities are the environmental ministries, which tend to discourage the productive use of forests, preferring their conservation. Although regulations allow the management of productive forests, the procedures are complex and subject to arbitrary interpretation by officials. The cost of formulating management plans is high, and there are long delays for approval and inspections. Many forest owners and producers prefer to by-pass these obstacles by operating in illegal, unsustainable ways. As most forests in Mexico are under some form of community ownership, the implementation of forestry interventions depends on having adequate institutional frameworks for community participation. The main barriers to sustainable management are therefore of the institutional type.

Table 3.17: Mitigation and financial performance of selected interventions in Mexico

Intervention	Area (million ha)	Mitigation (million tonnes of CO_2 equivalents /year)	Investment (million US$)	Net cost (US$/tonne of CO_2 equivalents)
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
Total with negative cost	***23.8***	***42.5***	***12 248***	
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
Total with positive cost	***41.1***	***28.7***	***4 859***	
Total	***64.9***	***71.2***	***17 187***	

Source: Based on Johnson *et al.,* 2009.

Barriers to electricity generation from renewable energy: Current regulations discourage power generation by small independent producers, by establishing a minimum capacity of 30 MW for entering into power purchasing agreements with the State-owned power monopoly, which have to be negotiated case by case. There is urgent need for policies that promote standard predefined contracts and tariffs ("feed-in tariffs") to encourage small generators to produce and sell electricity to the grid. Establishing simple small power purchasing agreements would be a useful first step. Lowering implicit discount rates from 10 to 3 percent by granting access to soft credits would improve considerably the financial performance of options requiring high initial investments.

Barriers to improved stoves: Appropriate training, technical assistance and follow-up are essential components of successful improved stove programmes. However, most ongoing programmes in Mexico provide funds for the purchase and installation of only cooking stoves. Standard designs do not consider cultural preferences and diverse cooking habits, and there is need for appropriate designs that are more appropriate for regional characteristics. Barriers in this area are both institutional and technical.

Barriers to efficient charcoal production: These include lack of a dedicated government programme, cultural resistance to the adoption of new production technologies, a need for training and technical assistance to ensure proper use and maintenance of the new technology, lack of capital to invest in kilns and equipment, and insufficient qualified/certified kiln builders. Overcoming these will involve policy, financing and institutional changes.

Impact on forests and forest industries of replacing fossil fuels with woodfuels

Impacts on forest productivity, health and conservation: The demand for wood that would arise from full implementation of all the interventions by 2030 is shown in Table 3.18. The overall demand is compatible with an estimated MAI of 58.9 million tonnes of dry matter (Table 3.12).

Table 3.18: Fuelwood demand in Mexico, 2030

Intervention	million tonnes of dry matter/year	million ha
Efficient charcoal production	8.1	2.8
Biomass electricity	34.8	12.0
Improved stoves	12.0	6.0
Fuelwood co-firing	0.3	0.1
Wood for energy	**55.2**	**20.9**
Forest management	10.4	9.0
Total demand for wood	**65.6**	**29.9**

Source: Based on Johnson *et al.,* 2009.

The extraction of 55.2 million tonnes of dry matter per year from 20.9 million hectares means an average of 2.6 tonnes of dry matter, or approximately 4.0 cubic metres per hectare per year. Standing stock in productive forests ranges from 80 to 250 cubic metres per hectare (averaging about 130 m^3). Thus, the mean average harvest of woodfuels calculated here represents 3.1 percent of the standing stock, to be achieved by pre-commercial thinning, clean cutting and the reclaiming of logging residues. The impact of this extraction on forest health and productivity will be positive. In addition, putting native forests under planned and intensive management may generate strong benefits in terms of protection against wildfires, overharvesting by poachers, and illegal deforestation.

Impacts on forest industries and forest producers: Lumber and stumpage prices will probably not be affected much by the increased use of wood for energy. The 2009 stumpage price is in the range of Mex$100 to $150 per cubic metre (US$7 to $12) for low-quality hardwoods, and Mex$400 to $800 per cubic metre (US$30 to $60) for top-quality softwoods. Small logs and cordwood are usually offered at Mex$200 to $300 per cubic metre (US$16 to $22) "piled-by-the-road", but most are left to rot because there is currently little demand for this product in the wood markets.

Competition for certain feedstock may increase if a strong wood-for-energy market develops. The pulp industry will be the most affected if cordwood and thinning prices go up in response to increased demand for energy. However, only a few plants in Mexico produce pulp from wood, and these obtain most of their feedstock as sawmill chips. The supply of cellulose-grade chips may increase if fuel chips are produced on a large scale, as it is relatively easy to sort fuel and pulp chips by sifting, and then to market them separately.

Turn-over and revenues for primary forest producers will increase significantly as the woodfuel market develops. Sales of logging residues and thinning will create a new source of revenue, allowing for faster recovery of the expenses associated with forest road construction, fire protection, and stand improvement practices such as pruning and cleaning. Sawmills will also benefit from the opportunities for selling residues, either unprocessed or converted into charcoal or fuel chips.

Employment in the forest sector resulting from the extended use of woodfuels by these interventions is shown in Table 3.19.

Investment in the forest industries has been lagging in recent years, since Mexico joined the North American Free Trade Association and has had to face strong competition from Canadian and United States forest products – especially pulp and paper. The development of a domestic woodfuel market will open ample new opportunities for investing in a new business line within the forest industry.

Table 3.19: Employment in the proposed interventions

Intervention	Labour costs (million US$, 2008 to 2030)	(million US$/year)	Jobs
Wood co-firing in coal power plants	194	9	3 522
Wood-based power generation	2 291	104	41 662
Charcoal production	2 433	111	44 229
Forest management	910	41	16 542
Wildlife management	3 033	138	55 138
Total	**8 860**	**403**	**161 093**

Source: Caludio Alatorre, personal communication.

Recommended investments and policy actions for substituting fossil fuels with woodfuels

In Mexico's institutional context, government agencies play three main roles in forest activities: regulation, promotion, and control. Regulation is the responsibility of the Ministry of Environment and Natural Resources, which issues permits for forest management and harvesting, registers forest product processors and wholesale vendors, and maintains statistics. Promotion is the responsibility of CONAFOR, which deals mainly with forest inventory, information, training, research and technology transfer, and administers programmes for subsidizing a wide array of forest activities. Control (policing) is by to the Federal Environmental Protection Agency (PROFEPA), which enforces forest and environmental law and applies sanctions.

CONAFOR is a new organization, devoting most of its efforts to implementing programmes with specific funding and goals. Wood energy issues are dealt with by a minor branch of CONAFOR, at the third hierarchical level and, as no specific programme is yet in place, this issue has neither a budget of its own nor specific targets or goals, other than the improved rural stoves programme, known as Dendroenergy. The Ministry of Environment and Natural Resources is a federal organization, with offices at the state level, many of which are understaffed and poorly equipped for dealing with the volume of paperwork they have to process. Delays and confusion over the issue of permits are frequent, and there is no institutional record keeping or register on which accountability could be based.

PROFEPA is also understaffed, and concentrates its activities on policing the environmental impacts of industrial activities, forest exploitation and land-use change. The three institutions have different goals and agendas, and do not usually work in coordination. Where legal and normative frameworks are not explicit or congruent, the Ministry of Environment and Natural Resources and PROFEPA tend to act in mutually incompatible ways.

Recommendations

Institutional strengthening:

- → Design and adopt a specific programme and budget for fostering woodfuel utilization, to be implemented by CONAFOR: The lack of such a programme means that no specific funding is assigned to woodfuel development.
- → Reinforce technical capacity at the Ministry of Environment and Natural Resources and PROFEPA: Understaffing and low technical capacities hamper the issuing of forest management permits, while lack of supervision leads to low-quality management.

Regulatory framework:

- → Streamline Ministry of Environment and Natural Resources procedures regarding the harvesting of logging residues: At present, two separate permits are required for harvesting and processing logging residues and for converting wood into charcoal.
- → Speed up the issue of permits for fuelwood recovery from shifting cultivation areas, by establishing simple norms and filling the gaps in existing norms for the transport and marketing of woodfuels from these areas: When the Ministry of Environment and Natural

Resources authorizes forest clearing for land-use change it does not issues corresponding permits for the production and sale of wood products, on the basis that the purpose of land clearing is not – or should not be – to produce wood for the market. Wood from cleared areas must therefore be burnt or left to rot.

→ Develop a norm or set minimum performance standards for improved cooking stoves and efficient charcoal kilns: In the absence of such as norm, the methods for producing charcoal and building cooking stoves are left to the judgement and capabilities of individuals.

Sector policies:

→ Define strategies and goals for substituting fossil fuels with woodfuels in selected industrial sectors and branches, including a schedule of implementation: The national programme for climate change does not include criteria for the replacement of fossil fuels with renewable fuels in the industrial sector. Such criteria are advisable, given the prospect of a rapid decrease in national oil and gas production.

→ Establish simple, standard small power purchasing agreements to ease the connection of small independent biomass-based power producers to the national grid: At present, each independent small power producer has to negotiate a separate power purchasing agreement with the State-owned power company, involving a lengthy and costly procedure, which discourages many companies from producing and selling excess power from renewable energy that could be fed into the national power grid at competitive costs.

→ Give priority to biomass-based power generation in the national load dispatch system: The load dispatch system's current order of priority is long-term contracted capacity, followed by low-cost fossil energy, and then hydropower. No priority is given to low-emission sources of energy.

Public investments:

→ Revise the programme of capacity building and replacement of public power utilities to include biomass-powered plants: The existing medium-term capacity expansion plan has a planning horizon of ten years and gives priority to building the lowest-cost power plants. This means that most new capacity is coal-fired, regardless of the impact on GHG emissions.

→ Include wood co-combustion capability in the specifications for new coal power plants: Currently no provisions are made for introducing technical specifications that allow for co-firing or alternate firing with biomass in new coal-burning power plants. This means that when coal becomes costlier or scarcer these plants have to burn fuel oil or be turned off.

Private investments:

→ Extend low-rate credit facilities to private investors in the woodfuels business: Woodfuels production typically requires relatively high up-front investment costs, and the development of new markets for the products. Both of these factors make access to credit difficult and costly. Access to low-cost sources of credit and government-backed collateral may encourage private investments.

→ Promote links between forest owners and woodfuel consumers, to ensure sustained supplies and equitable distribution of benefits: Forest owners, which are mainly communities and *ejidos*, have very little capital and very low levels of organization. It is difficult for them to enter into businesses that require long-term planning and initial investment. Their association with woodfuel consumers providing capital and managerial skills could be of great benefit for development of the woodfuels business.

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