10 Forests and Bioenergy Production

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Abstract: The role of global forests as an energy source is increasing. The use of woody biomass for power, heat, and transport fuels can vitalize the forest sector and link it more closely with the energy sector regionally and globally. Particularly in the northern hemisphere the accumulating growing stock allows the more intensive use of forest biomass for biofuels. Forest-based energy production can reduce the use of fossil fuels and reduce greenhouse gas emissions. The over-utilisation of forest ecosystems, however, can jeopardise the sustainable development of forests and societies dependent on forests. Therefore, forest energy policies have to be based on the principle of sustainable development, ensuring both economic and environmental longevity in the use of the resource. The forest research and development organizations are challenged to conduct multidisciplinary work that links high quality economic, ecological and social research with the operational practices of bioenergy production. This is essential to respond to rapidly increasing information needs regarding the role of forests in the global energy supply.

Keywords: bioenergy, biofuels, wood-based fuel, sustainability

10.1 Energy – Main Product of Forests

Mitigation of climate change, the scarcity and high price of fossil fuels, and securing the energy supply have brought forests and other bioenergy sources into focus in the global energy discussion. The use of woody biomass as an energy source has a long tradition. In fact, wood has been the most important energy source for humankind, excluding the short industrial era that began in the 18th century. This chapter outlines and discusses the potential opportunities and constraints on global forests as a sustainable source of renewable energy.

In this discussion, "wood fuel" is any solid or liquid fuel made from wood. This term is used interchangeably with "biofuels," which are any solid or liquid fuels made from biomass. "Fuelwood" is unprocessed sticks, branches, and logs (split or unsplit) that are burned as firewood. Strictly speaking, "biomass" is any unprocessed organic material from forests, including roundwood, branches, tops, and stumps, but is often used to refer to non-roundwood material (harvesting residues) destined for processing into biofuels (but when costs are low, roundwood is sometimes also processed into biofuels instead of traditional forest products).

Total global wood consumption in 2007 was 3.6 billion m^3, with over 50% of this (1.9 billion m^3) being used for wood fuel. Globally, it is estimated that 36.2 EJ of the world's energy production comes from trees and shrubs: ~30 EJ from traditional fuelwood, 3 EJ from charcoal production, and only 1 EJ from modern solid biofuels, such as pellets and chips (Sims et al. 2007). There is great variation within and between countries and continents in the proportions of wood used in the forest industry as roundwood compared to wood fuel for energy: 90% (603 million m^3) of total roundwood production (672 million m^3) was used as wood fuel in Africa, whereas only 21% (153 million m^3) of total roundwood production (728 million m^3) was used as wood fuel in Europe (FAOSTAT 2009).

Current global energy consumption has doubled since the early 1970s, and its accelerating rate of growth is evident in the ~20% increase in consumption in only the first eight years of the current mil-

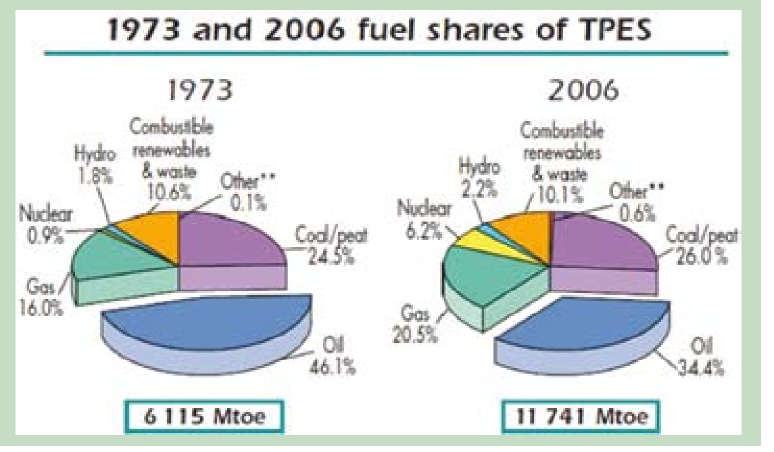

Figure 10.1 Evolution from 1971 to 2006 of world total primary energy supply (TPES) by fuel (Mtoe) (IEA 2008).

lennium (IEA 2008). Although fossil fuels (oil, coal, and natural gas) account for over 80% of global energy consumption (Figure 10.1), renewable fuels, including biomass, have maintained their market share (10%) over the decades. Areas of the world that depend on imported fossil fuels to meet their energy needs will be very vulnerable if exportation policies or international crises affect supplies. In addition, fossil fuel production and consumption are a major source of greenhouse gas (GHG) emissions, and are thus a significant contributor to climate change.

Reducing greenhouse gas emissions is essential, and nations are implementing policies to meet their commitments to international goals for mitigating climate change. These include increased international cooperation, energy conservation, more efficient use of energy, and development of alternative energy sources. Within this context, the efficient use of wood biomass as a renewable energy resource is one favourable strategy for substituting use of non-renewable fossil fuel energy resources.

In developing countries, wood fuel often contributes to over 50% of final energy consumption, and is usually directly combusted as either firewood or charcoal. For example, 53% of Senegal's final energy consumption in the early 2000s was of firewood and charcoal (IDA 2007). However, large-scale charcoal production can cause severe environmental, economic, and social problems. In Senegal, forest cover diminished by 30 000 ha/year and the resultant degradation of the rural environment led to migration to cities and to a reduction in the capacity of forest ecosystems to sequester carbon (IDA 2007). Alternatively, good management of fuelwood plantations contributes to the sustainable long-term supply of woody biomass for energy production. For example, plantation-based charcoal production has replaced fossil carbon (coke) in some industrial processes, such as parts of the pig iron industry in Brazil (PCF 2002).

In countries with well-developed forest industries, much of the wood-based energy generation takes place within sawmill and pulp sectors, often using waste industrial by-products for fuel. Energy has become an increasingly important forest product because of the rise in global energy prices since the beginning of this millennium and concurrent weaknesses in traditional forest product markets. This has driven companies to look for cost-savings through generating their own energy, and diversified markets through the sale of energy outside of the forest sector. For example, industrial by-products from the forestry sector accounted for 88% of the 259 PJ of wood-based energy generation in Finland in 2007 (METLA 2008); more than half of this (158 PJ) was generated from waste liquors from the pulp industry, and more than another quarter (69 PJ) came from the sawmill industry.

10.2 Drivers of Intensive Forest Energy Utilisation

10.2.1 Mitigation of Climate Change

The need to mitigate climate change through reduced GHG emissions from fossil fuels is a major motivation for increasing the utilisation of forest-derived bioenergy. Fossil fuels can be partly substituted by wood in energy production. Whereas fossil fuels are non-renewable and the carbon they release to the atmosphere contributes to an increase in carbon dioxide (CO_2) concentration, the new forest growth after harvesting biomass will take up, and therefore sequester, an equivalent amount of CO_2 to that released during its combustion.

Use of forest energy is strongly interconnected to other mitigation measures in the forest sector and also, through energy wood plantations, to the ag-

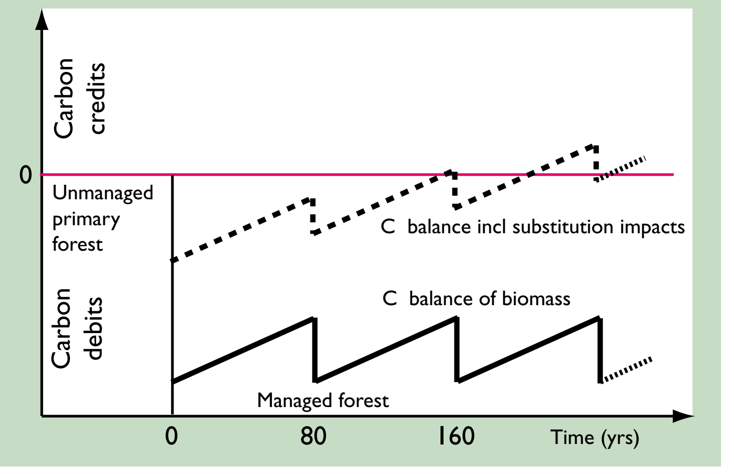

Figure 10.2 The combined effects of the use of forest energy and other mitigation activities should be considered as a function of time. This schematic illustration was kindly provided by Kim Pingoud.

ricultural sector. Forests store carbon and thus an increase in the use of bioenergy requires that three other mitigation factors – forest area, site-level carbon density, and landscape-scale carbon stocks – should also be maintained (Nabuurs et al. 2007). The first factor, forest area, is not threatened by sustainable fuelwood use because the procurement areas remain part of the commercial forest. There may be trade-offs, however, between site-level carbon density and forest energy. For example, if the initial carbon stock is high (e.g., in an unmanaged forest) and the regrowth after harvesting is slow, then the compensation time resulting from the combined impact of lower carbon stocks in the resultant managed forest and substitution can be even longer than the rotation time (Pingoud 2009, Figure 10.2). Finally, the impact on landscape-level carbon stocks may be either positive or negative; for example, procurement of energy wood reduces carbon stocks but may also (in the case of thinning small-sized trees) reduce the risk of natural disturbances such as fire that could reduce carbon stocks even further.

As a whole, the mitigation potential of forest energy is significant; estimates of the benefits range from 420 to 4400 MtCO_2-eq in 2030, which is 5% to 25% of the total CO_2-eq emissions from electricity production (Nabuurs et al. 2007).

10.2.2 Combined Forest Industry Product and Energy Generation

In the industrialised countries, the forest industry is often the largest producer and user of wood-based energy. Production of sawn goods generates equal amounts of timber and by-products. If no pulp and paper industry is located near a saw mill, all by-products are available for energy generation. At the mill, energy is needed for drying sawn goods. In chemical pulping, lignin is extracted from woody biomass and converted into energy. This means that many pulp mills actually produce more heat and electricity than they need at the site. Both sawmill and pulp industries have found supplemental business activities, for example, supplying hot water for district heating of surrounding communities, or providing electricity to a national grid, which can add significantly to their business success.

In many countries, such as Finland and Canada, there is a need to restructure and diversify the forestry sector. In the 2000s, the prices of many pulp and paper products have decreased dramatically, whereas prices of energy products have increased. Wood-based bioenergy has the potential to become a growth industry for the forest sector in a number of countries (Vogt et al. 2005). In Finland, for instance, the value of pulp and paper production was much higher in the beginning of this millennium than that of wood-based energy generation, but the difference has diminished continuously during this century's first decade. As a result, forest industries have invested in biomass-based energy generation, as well as research and development of new energy products, such as biodiesel (Hetemäki 2008). Development of new policies aimed at supporting the growing demand for biomass energy will not only be required, but will present governments with an opportunity to enact legislation to expand the scope of their forest industries and to make them more competitive in future markets.

10.2.3 Biomass-Based Transport Fuels Reduce Oil Dependency

Increased production of liquid transportation fuels could reduce the dependency on crude oil imports. First-generation biofuels, e.g., bioethanol from grain and vegetable oil, or animal fat-derived biodiesel are already on the market and their production technology is well established. Due to energy-intensive cultivation and refining processes, their energy balance (energy input in the system/energy content of produced fuel) has been uneconomical and, in a few cases, input energy needed exceeds the energy content of the fuel.

However, woody biomass can be used as feedstock for liquid transportation fuels, and has several advantages: its use does not affect food production or price, and the conversion into energy can have a more favourable energy balance. There are two main routes to produce liquid biofuels from ligno-cellulosic biomass: biochemical and thermochemical (European Biofuels Platform 2008). In a thermochemical process, woody biomass can be gasified to syngas (containing carbon monoxide, CO; hydrogen, H_2; and CO_2), which can then be cleaned and further processed through Fischer-Tropsch (FT) synthesis to produce a variety of waxes that can be converted to diesel oil. Another thermochemical route is based on pyrolysis, from which bio-oil can be obtained. Pyrolysis oil can replace heavy fuel oil. In a biochemical process, ethanol can be produced from the ligno-cellulose in wood. This involves grinding the biomass, pre-treating it, and using hydrolysis to crack the cellulose into sugars. These sugars are then fermented using bacteria and yeast to produce ethanol. Biogas can also be produced from biomass, but the suitability of woody biomass for biogas production is poor (IEA Bioenergy 2008).

In addition to woody biomass, black liquor can be used as a feedstock for liquid biofuel production (IEA Bioenergy 2007). It is far more homogenous material than residual forest biomass or even roundwood. Its conversion can be integrated with pulpmill processes, and excess heat can be used in the pulping process. However, the use of black liquor as raw material for gasification and further liquid biofuel production can create an energy deficit for the pulp mill. This calls for the use of other feedstocks, such as residual forest biomass, especially in heat generation (IEA Bioenergy 2007).

So far, production of these second-generation biofuels is only at an experimental stage, and there are only a few pilot plants in operation. For example, a pilot plant producing diesel and using woody biomass as feedstock was officially opened in June 2009 in Varkaus, Finland. If technologically and economically successful, the first full-scale production units are expected to start up around the mid-2010s. Each of these units could use 1 to 2 million m^3 of woody biomass as feedstock and produce 100 000–200 000 tonnes of diesel annually.

In the United States of America (USA), construction of one of the world's first commercial-scale cellulosic biofuels plants began near Soperton, Georgia, in 2007 (Range Fuels 2009). The plant uses woody biomass and is anticipated to produce <38 million litres per year of ethanol and methanol in the second quarter of 2010, and 380 million litres of ethanol and methanol per year when fully operational.

10.2.4 Socio-Economic Benefits

Globally, there is growing interest in the socio-economic benefits of renewable energy, including using wood to generate energy. The socio-economic implications of using wood for this purpose are multifaceted, and include economic issues, such as employment and monetary value, as well as social, cultural, institutional, and environmental issues (Domac et al. 2005). Globally, policy makers are becoming increasingly aware not only of the potential economic benefits of using wood for energy, but also its potential commercial implications. Domac et al. (2005) argue that the social perception regarding the sustainability of wood energy depends on how the accompanying technology is perceived by society, and how societies stand to benefit from it, with primary driving forces in support of wood energy being job creation, contribution to regional economy, and income improvement. Larger scale issues of carbon emissions, environmental protection, and security of supply are of importance, but the primary drivers of forest bioenergy at community and regional levels are likely to be socio-economic in nature (Domac et al. 2005).

10.3. Resources and Trade of Wood Energy Biomass

10.3.1 Global Forest Energy Resources

Bioenergy or wood energy systems are complex, and involve a number of variables that have to be accounted for, including socio-economic benefits, climate change mitigation, ecological values, technological efficiency, and the interplay between industry and policy (Domac et al. 2005). Given this complexity, considerable uncertainty exists in estimating the potential for renewable energy, including bioenergy, at global and regional scales (de Vries et al. 2007). This uncertainty is a result of the various inter-sectoral

Table 10.1 Global estimates of the annual forest energy potential.

Publication	Temporal scope	Type of potential	Estimate, EJ	Origin
Yamamoto et al. 2001	2100	theoretical	379	modern fuelwood
Berndes et al. 2003	Present–2030	theoretical/technical	c. 5–15	forest residues from industrial roundwood and fuelwood/charcoal production
Berndes et al. 2003	2050–2100	theoretical/technical	c. 5–50	forest residues from industrial roundwood and fuelwood/charcoal production
Berndes et al. 2003	2050	theoretical/technical	c. 50–100	unspecified forest biomass
IEA Bioenergy 2007	Present–2050	economic	30–150	forest residues
Smeets & Faaij 2007	2050	theoretical	76.7	surplus forest growth + logging residues
Smeets & Faaij 2007	2050	technical	70.1	surplus forest growth + logging residues
Smeets & Faaij 2007	2050	economic	20.8	surplus forest growth + logging residues
Smeets & Faaij 2007	2050	economical-ecological	5.1	surplus forest growth + logging residues
Nabuurs et al. 2007	2020–2050	technical	12–74	primary residues
Nabuurs et al. 2007	2020–2050	economic	1.2–14.8	primary residues

Source: Anttila et al. 2009.

drivers at play, including resource characteristics (availability and accessibility), geographical differences (land use and cover), techno-economic factors (scale, labour costs), and institutional factors (policy, legislation) (de Vries et al. 2007). Consequently, it is often difficult to accurately quantify and assess the available and sustainable level of harvest of wood for energy. These factors explain the great variation in estimates for global forest energy resources.

Yamamoto et al. (2001) simulated regional bioenergy supply potentials. Because the demand for wood biomass will increase in developing countries, the area of mature forests will decrease in many areas. Mature forests are predicted to disappear from Centrally Planned Asia, the Middle East and North Africa, and southern Asia. Consequently, the potentials of fuelwood in those areas will be low in the future. According to the simulations, the theoretical global potential of modern fuelwood will be 379 EJ/year in 2100. More than half of the potential (199 EJ/year) will be in Latin America, and 75 EJ/year in sub-Saharan Africa, while the potential in western Europe, Japan, Centrally Planned Asia, the Middle East and North Africa, and South Africa will be only 0–6 EJ/year.

Earlier work by Yamamoto's team was included in a review by Berndes et al. (2003), who evaluated 17 studies of biomass energy potential. The authors noted that the potential from forests depends greatly on the basic approach of a study. In demand-driven studies, which took the anticipated future demand of industrial roundwood as a restriction for the potential, much lower potentials were reported than in the resource-focused studies, which were based on forest growth, accessibility, and competition with other uses. The annual forest energy potentials in the first-mentioned studies ranged from a couple of EJ presently, to some 50 EJ in 2100; whereas in the latter ones, the range was from about 50 EJ to over 100 EJ in 2050 (Table 10.1).

In a recent report by the International Energy Agency (IEA) (Faaij 2007), a range for energy potential of forest residues was given. The upper limit was estimated to be 150 EJ, representing technical potential, while the lower limit is 30 EJ, including limitations with respect to logistics and standards for cuttings. In total, the most pessimistic estimate for global biomass potential was 40 EJ, and the most optimistic was 1100 EJ. Average potential would be between 200 and 400 EJ, if there were a common goal of more intensive use of bioenergy around the world.

Smeets and Faaij (2007) estimated forest energy potential in 2050. The theoretical potential based on medium demand and medium plantation establishment scenario was 6.1 Gm^3/year (71 EJ/year), technical potential 5.5 Gm^3/year (64 EJ/year), and economical potential 1.3 Gm^3/a (15 EJ/year). Supposing that ecological restrictions are also taken into account, the resources would not be enough to meet the demand. The theoretical, technical, and economical potentials consist mostly of surplus forest growth.

Nabuurs et al. (2007) reviewed several studies in order to examine the possibilities of forest energy to mitigate climate change. They concluded that the technical potential of primary biomass for energy from the forest sector would be 12–74 EJ. The economical potential would be only 1.2–14.8 EJ.

At a sub-global level, forest resources, technology, energy infrastructure, national laws and policies, and many other issues affect the use and development of the renewable energy sector. For example, the extent of wood biomass use as an energy resource varies among the European countries, and the tech-

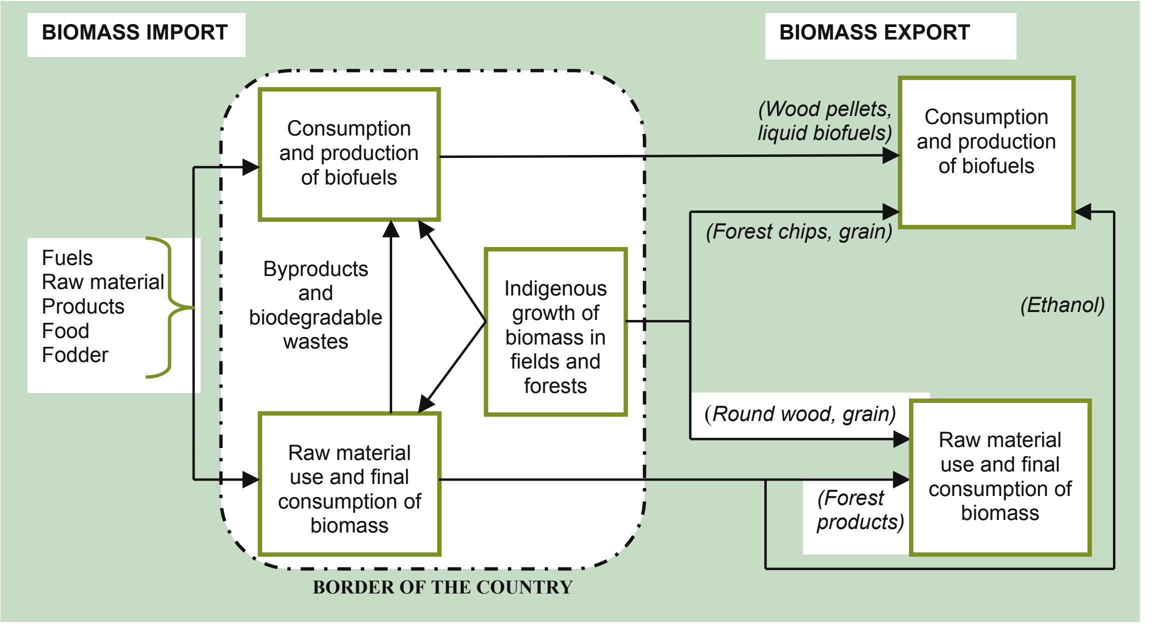

Figure 10.3 An illustration of biomass streams within a country and between countries. Products presented in brackets represent examples of products (Heinimö 2008).

nically available forest energy potential in the 27 European Union (EU) countries was estimated to be 1.5 EJ (36 Mtoe, or 187 million m³) (Asikainen et al. 2008).

10.3.2 Trade of Energy Biomass and Biofuels

In many areas, both regionally and nationally, biomass production potential cannot meet demand; this is especially so in industrialised countries such as the USA, Japan, and nations that are members of the EU. On the other hand, there are areas where biomass production potential exceeds local demand, such as many parts of sub-Saharan Africa and Latin America. However, it is often more logical to consume biomass locally than to export it, especially when it can be used to replace fossil fuels. (Canada may be an exception, as it has not only large fossil fuel reserves, but also abundant hydroelectricity and large agricultural and forest biomass potential compared to its relatively small population.) Although only a limited proportion of global bioenergy consumption is based on imported biomass or biofuels, the volume of international biomass trade will increase significantly in the future. Notwithstanding the predominant use of locally produced biomass for bioenergy, a significant number of cross-border streams of diverse forms of biomass – raw, processed, or within products – together with their various end-uses, constitute a complex field that is outlined simply in Figure 10.3.

Imported biomass, or a product that includes biomass, can be processed in the import country into more refined final products, which are then consumed in the country or exported onward. Foreign biomass that has entered the country can be used as fuel, e.g., wood pellets. Nevertheless, some products, such as ethanol or some forest industry by-products, can be used for both energy and raw material purposes, making it necessary to know where the products are consumed. Biomass is also traded for biofuels production, e.g., palm oil for biodiesel, and this will be a more common trend when large bio-refineries produce liquid biofuels for road transport. Eventually, most of the products that include biomass end up in recycling and energy production.

Ethanol, vegetable oils, fuel wood, charcoal, and wood pellets are the most important products that currently are traded internationally for energy purposes. Nevertheless, the international trade of these products is much less than the international trade of biomass for other purposes. Table 10.2 depicts the volumes of global production and international trade of various biomass products in 2004–2006. Most of these products are mainly consumed locally in the producing country, but a considerable proportion of the total production of sawn timber, paper and paperboard, palm oil, and wood pellets is exported.

Direct trade of solid and liquid biofuels is growing rapidly. In the past, the volume of indirectly traded biofuels was significantly higher, e.g., three times greater than the direct streams in 2004. Rapid growth is associated especially with the trade of liquid biofuels (ethanol and biodiesel, for which the demand has grown tremendously in recent years in the EU and

Table 10.2 An overview of world production and trade volumes of selected agricultural and forestry commodities with potential energy application in 2004–2006.

Product/year	Unit	World production			International trade volumes		
		2004	2005	2006	2004	2005	2006
Industrial wood and forest products:							
Industrial roundwood	Mm³	1656	1709	1684	121	131	129
Wood chips and particles	Mm³	215	222	232	39	43	44
Sawn timber	Mm³	421	426	427	133	134	133
Pulp for paper production	Mt	190	189	190	42	42	43
Paper and paperboard	Mt	355	354	354	111	113	114
Agricultural products:							
Maize	Mt	727	713	695	83	90	95
Wheat	Mt	633	629	606	118	121	125
Barley	Mt	154	141	139	22	25	24
Oats	Mt	26	24	23	3	3	3
Rye	Mt	18	15	13	2	2	2
Rice	Mt	607	632	635	2	2	2
Palm oil	Mt	31	34	37	23	26	29
Rapeseed	Mt	46	50	49	9	8	11
Rapeseed oil	Mt	15	16	17	2.6	3.1	4.1
Solid and liquid biofuels:							
Ethanol	Mm³	40.8	46.0	51.1	2.7	3.0	4.3
Biodiesel	Mt	2.3	3.6	5.3	n.a.	0.2	0.4
(2.7–3.8)							
Fuel wood	Mm³	1771	1824	1827	4	4	4
Charcoal	Mt	46	43	43	1.1	1.3	1.4
Wood pellets	Mt	4.0	5.5	7.8	1.5	2.4	3.6
		(3.7–4.8)	(4.6–6.5)	(7.1–8.4)	(1.2–1.7)		

Source: Heinimö and Junginger 2009.

the USA). This has triggered the export of ethanol (mainly from Brazil), vegetable oil (e.g., palm oil and soybean oil), and biodiesel from southeast Asia and Latin America. Also, pellet exports from Canada to the EU (next to large-scale intra-European trade) show strong growth rates. The emerging production of torrefied wood and pellets made of torrefied wood could replace coal in large plants which can further accelerate the growth of direct trade. It is expected that direct trade volumes of biofuels will overtake indirect trade within a few years.

The estimated total volume of internationally traded biofuels was approximately 0.9 EJ in 2006, and hence biomass trade is still a long way from its estimated long-term maximum potential of 80 to 150 EJ/year. However, given the current policy developments to stimulate the use of biofuels in, for example, the EU and the USA, and given current high fossil oil prices that are expected to continue to increase as world reserves decrease, a continuing increase in biofuel trade can be expected in the near future. Simultaneously, however, some policies may slow the rate of increase in total international bioenergy trade. For example, development of sustainability criteria for biofuels (such as the recently proposed revision to the RES directive, i.e., directive of the European parliament and of the council on the promotion of the use of energy from renewable sources) and changing trade tariffs for commodities such as ethanol may temper or even reduce trade growth for some specific biofuels.

10.4 Technology of Supply

10.4.1 Traditional Use of Firewood

Burning firewood for cooking and heating is still the most significant use of wood in many parts of the world. Even in many industrialised countries, the volumes of domestic firewood consumed exceed the industrial use of chips for energy. The technology for harvesting, preparing, and burning firewood is simple and cheap, enabling practically all people, especially those in rural areas of the world, to use this form of energy.

Antti Asikainen

Photo 10.1 Fuelwood market in Gambia.

Box 10.1 From deforestation to sustainable fuelwood production

Brazil has vast biomass resources and produces 30% of its energy from biomass (Lora and Andrade 2007). There is a long tradition of producing charcoal for pig iron industries in the state of Minas Gerais. About 30% of wood produced in the state is utilised in the charcoal-based iron and steel industry (PCF 2002). In the 1980s, charcoal production reached a level of 20 million m^3/year, leading to deforestation of 1 million ha of natural forest annually. The raw material for the charcoal industry has shifted almost totally from the use of natural woody biomass to fuelwood plantations, where Eucalyptus is grown.

In order to reduce deforestation, the State of Minas Gerais passed a law that required integration of charcoal supply with industrial timber plantations by 1998, and phasing out the use of native forest resources for charcoal by 2000.

The work safety issues of charcoal production have been criticised (Kato et al. 2005). The work process is still labour-intensive and the workers are subject to accidents and carcinogenic substances when exposed to the smoke and dust of the charcoal production process.

This case from Brazil shows that by legislative measures, unsustainable wood energy production can be converted to more sustainable practises. Improvements in sustainability have many dimensions: In addition to the ecological dimension, such aspects as work safety and human health have to be considered.

In the developing world, hand tools such as axes, machete-type knives, and bow saws are still appropriate harvesting tools. Chainsaws are much more efficient, but purchase, maintenance, and fuel costs can substantially increase wood fuel costs, and availability of spare parts can be poor. Fuelwood is often transported by being carried by people or animals. Over longer hauling distances, trucks and pickups can also be used. Firewood can be traded in local markets or delivered directly to end-users (Photo 10.1). Charcoal production, in which wood is carbonised in simple rural kilns or larger industrial settings, is another traditional way of converting biomass into a biofuel with a higher energy density than wood. There are examples of the unsustainable use of woody biomass for traditional firewood and charcoal production in some parts of the world, especially in areas with sensitive ecosystems or where biomass


Robert Prinz

Photo 10.2 Bundling of logging residues.

availability is low but population requirements are high; furthermore, there are also health risks associated with the manual work involved in harvesting and processing this woody biomass with exposure to particle emissions in the smoke from the combustion process (Kato et al. 2005). However, there are also examples of successful reforestation and sustainable management of fuelwood plantations in, for example, Africa and South America (IDA 2007, PCF 2002). See Box 10.1 on charcoal production in Brazil.

In the industrialised countries in small private forest holdings, the chainsaw, together with farm tractor-based transport of wood are the dominant technologies. Splitting of firewood is done using an axe. In recent years, the use of farm tractor-powered cutting and splitting machines have increased. Such machines can be owned by individual farmers or by a cooperative to produce firewood for not only for their domestic use but increasingly for the commercial fire wood markets. When firewood is produced in large quantities, single-grip harvesters and forwarders are used in the harvesting of firewood. Splitting and drying of wood is done in terminals.

10.4.2 Harvesting of Residual Forest Biomass

In most countries, the greatest amount of biomass to be used for bioenergy is extracted from final fellings. The methods for harvesting residue biomass produced by logging roundwood depends on the logging method and the degree to which the supply chain for residue removals is integrated with roundwood removals. For example, whole trees can be felled and skidded or forwarded to landings, where they are delimbed and roundwood is separated from the resultant residues; cutting can be manual or mechanised. However, in Nordic countries, where supply chain efficiencies for production of both roundwood and resultant residue biomass is perhaps greatest, mechanised cutting is a prerequisite for effective recovery of logging residues. Single-grip harvesters typically pile the residues in heaps on the logging site, the material is seasoned for a few weeks during spring and summer months to reduce its moisture content and allow needles to drop onto the ground, and then the residue is easily loaded using a forwarder (load carrying forest tractor) or a farm tractor equipped with a grapple-loader and forest trailer, and removed from the logging site (Wigren 1992, Asikainen et al. 2001).

Janne Häikiö

Photo 10.3 Single-grip harvester in energy wood harvesting.

Logging residues can also be bundled before being removed from the site (Photo 10.2). This reduces the space required to transport the biomass and increases the payload during forwarding and long-distance transport. In addition, the loading and unloading in forwarding and trucking is much faster with compacted material.

Standard forwarders can transport both loose and compacted logging residue to roadside landings and pile it for longer storage before chipping and transportation. For loose residues, the grapple is often modified so that supporting beams connecting the ends of forks are either removed or moved inwards in the grapple to give better penetration in the residue piles.

Spruce stumps can also be harvested for energy after final felling. Stumps are removed using excavators equipped with a lifting device (Laitila et al. 2008). Stumps are removed in one piece or are split into two or more pieces before being lifted. Splitting considerably diminishes the lifting force required, and a smaller area of humus is disturbed and lifted with the coarse roots. Stumps are stacked in heaps at the site for drying, and also to allow rain and wind to remove soil from stump wood. Forwarding is carried out using traditional forwarders.

10.4.3 Harvesting of Forest Energy Biomass from Early Thinning

When standing trees are harvested for energy, additional felling and processing is needed, compared to harvesting logging residues. The most common method currently used in Europe consists of felling and bunching trees using a single-grip harvester or a forwarder with a grapple that is modified for handling energy wood (Photo 10.3) so that it can hold two or more trees in the grapple and bunch them for forwarding. Manual felling using chainsaws equipped with felling handles can also be used (Heikkilä et al. 2005).

More recently, harwarders, i.e., combined harvester-forwarder machines, have been introduced for harvesting small trees for energy; harwarders fell the trees and then cut them into ~6 m lengths for forwarding. The same machine then also forwards the material to the landing, and thus only one machine unit is needed to perform the operation. Over short forwarding distances, and in small stands, harwarders are emerging as a competitive alternative to manual felling or harvesters with modified grapples.

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Photo 10.4 Chipping at the roadside landing.

10.4.4 Comminution of the Material

Biomass is chipped into small (10 to 100 mm) particles to enable efficient handling of feedstock and to improve its combustion properties. Once chipped, heat and power plants can store and feed the material into the burning chambers of the plant. Chipping can take place in the forest: the in-the-woods chipper loads (feeds) biomass into the chipper, chips the material, and transports it to the roadside. In-woods chipping was popular in Nordic countries in the 1990s, but is now rarely used in Finland and Sweden. This kind of machine can only operate economically on flat forest land and in thinnings, and was found to be too heavy and expensive a unit to use for final fellings or on coarse terrain.

Most chipping is now carried out at roadside landings (Kärhä 2007). Chippers can be mounted on trucks, or smaller units can be operated by a tractor (Photo 10.4). The optimal size of a chipper depends on the volume of operation and on the condition of the forest road network. Chippers blow chips directly into chip trucks, which transport the chips to the plant. The main problem with chipping-trucking systems is the interaction between chippers and trucks: the chipper cannot operate if an empty truck is not available, and the truck has to wait if the chipper has a breakdown. Also, the direct loading time of the truck depends on the productivity of the chipper.

Chipping can also be done at a terminal located between the raw material source and the end-use facility. In this case, uncomminuted material is first hauled to the terminal and stored there. Chipping at the terminal can be performed by either stationary or mobile chippers. Stationary chippers are used when terminals are big (i.e., supplying over 100 000 tonnes per year). Chipper productivity is higher at terminals because the chipped material can be blown on the ground and hence there is no need for a truck to be present for immediate loading. If the terminal is located at the end-use facility, then no additional trucking is needed and the material can be fed directly into the feeding storage area using front-end loaders. If the terminal is located between biomass sources and the end user, or if the terminal serves several end users, then loading of trucks and hauling must be performed.

10.4.5 Costs of Supply

Bioenergy projects must be economically viable for the different actors in the value chain (Lunnan et al. 2008). Woody biomass used for energy generation must be able to compete with other uses, e.g., pulp and paper, at the same time the energy produced from biomass must be as cheap as or cheaper than energy produced from competing energy sources. The costs of energy feedstock and market prices of energy products are changing all the time, the cost of fossil fuels, especially, show large variations.

Wood fibre, including mill residues and forest harvesting residues, must be recovered and transported to bioenergy facilities. Furthermore, the availability of fibre can be extremely variable between regions. This can pose challenges to a number of countries, especially if much of the fibre is inaccessible or the recovery rate of fibre is low, making it financially non-viable. For some biomass sources, such as residues from mills, the cost of transportation would be relatively small (Welke 2006). However, for sources such as harvesting residues, which has to be collected over large areas and transported longer distances, costs could be considerably high, and perhaps even prohibitive in some regions (NCASI 2006).

The technology to convert wood to energy is relatively new and expensive (Caputo et al. 2005). Often it is much more expensive than generating energy from fossil fuels, such as coal or oil (Mann 2004). In fact, a study by Hughes (2000) found that in most cases, the cost differential between biomass and coal is not sufficient to generate a profit, especially when operating and maintenance costs are included in the equation. Thus, there is a constant challenge to maintain competitiveness with conventional energy systems (Roos et al. 1999). This is what drives the bioenergy sector's reliance on cheap residues from milling operations (Tan et al. 2008).

However, in the Nordic countries, the use of primary forest biomass, such as logging residues, stumpwood, and whole trees from thinnings, has become cost-competitive, especially for the inland energy plants, where coal becomes more expensive due to longer transport distances. In Finland, the number of plants using primary forest biomass as a fuel has grown by hundreds since 2000 (Asikainen and Anttila 2009).

Factors affecting the costs of biomass supply can be grouped into two main components: (*i*) the annual availability and quality of (woody) biomass around the planned bioenergy plant, and (*ii*) costs to the user of feedstock associated with purchase, harvesting, processing, transportation, and storage. In areas where use of especially primary forest residues is starting, the net annual increment and industrial use of wood defines the available resources (e.g., see Asikainen et al. 2008). As the use of woody biomass for industry and energy increases, the competitiveness of biomass becomes an important factor in reducing the availability of fuels. For example, the price of biomass decreases when demand for pulpwood is very low, and hence the energy industry can afford to purchase the wood for energy generation. Under normal pulpwood market conditions, however, less wood is available for energy at a reasonable price.

Harvesting, chipping, and transport costs of logging residue chips vary between EUR 20 and 25 /m^3 in eastern Europe (Asikainen et al. 2008). In western Europe, costs are EUR 30–35 /m^3 due to higher labour and fuel costs. Chips made of small-diameter whole trees add EUR 7–10 /m^3 to the cost of chips made of logging residues because of felling and bunching costs. Today, the typical price paid for fuel chips in Finland is EUR 30–40 /m^3 (EUR 15–20 /MWh) and thus chips made of logging residues are cost-competitive fuels, whereas chips made of small-diameter trees need to be subsidised. In the Czech Republic and Poland, wood fuels are only competitive with coal because of current subsidies (Asikainen et al. 2007).

10.5. Sustainability and Certification of Forest Woodfuels

10.5.1 Sustainability of Forest Woodfuels

Production and harvesting of woodfuels from forests can lead to substantial global and national benefits, including climate mitigation and improved security of national energy supplies. Local benefits include employment and business opportunities, access to fuelwood for subsistence use, wildfire risk reduction, and facilitation of and reduced costs for silvicultural practices, such as site preparation and planting; stump harvesting may also be used to reduce root rot problems. A number of potentially adverse economic, social, and environmental impacts need to be considered, however, if utilisation is to be sustainable (Egnell et al. 1998, Richardson et al. 2002, Lattimore et al. 2009).

Important environmental concerns include forest degradation because of an imbalance between growth rates and harvesting rates, and decreased site productivity caused by nutrient losses from shorter rotations or removal of small trees and slash that would otherwise be left on site. Fertilisation and wood ash recycling can be used to sustain soil fertility, but it is costly and can cause undesirable impacts in some cases by, for example, disturbing natural flora and faunal communities. Removal of residues and logs of low quality may also jeopardise the amounts of substrate required as food and habitat by organisms dependent on these deadwood components.

Additional interventions in the forest to extract biomass (e.g., after seasoning) or to perform compensation fertilisation increase the risk of physical damage to the soil, which in turn can decrease productivity and lead to erosion and sedimentation

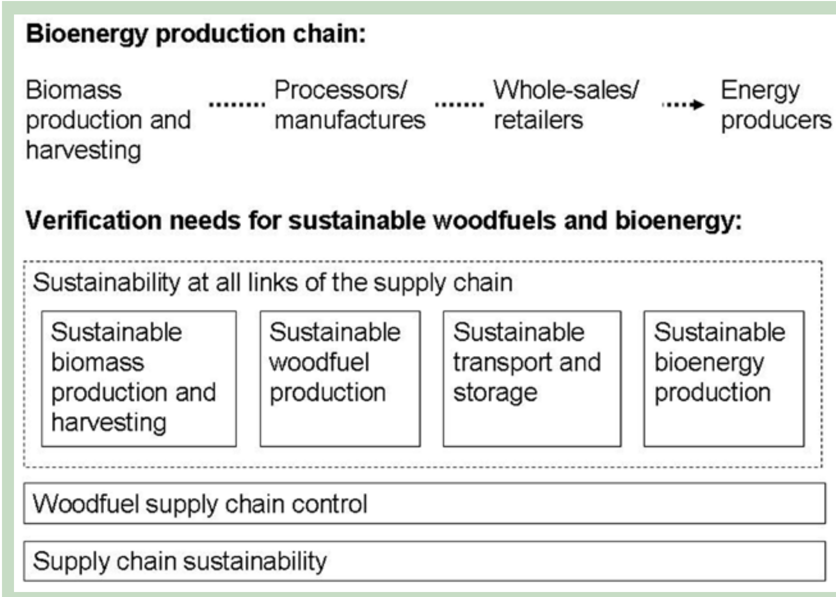

Figure 10.4 The bioenergy production chain and various types of verification needed to provide proof of sustainable bioenergy production.

problems in local watercourses. The effects of stump removals on soil quality are especially of concern.

Where the objective of forest management evolves from solely roundwood production to include woody biomass for energy, management treatments may also be intensified to increase productivity or to compensate for increased biomass removals by, for example, increasing application of site preparation, fertilisation, vegetation management, use of exotic species or, where permitted, perhaps even use of Genetically Modified Organisms (GMOs). There may even be cases where natural forests are converted to energy plantations, possibly leading to changes to or reductions in soil carbon stocks and biodiversity, and sometimes displacement of people dependent on the natural forests. Establishment of energy plantations on agricultural land may likewise lead to ecological and social changes that may be positive or negative, depending on the specific land and people affected.

In areas where it is scarce, considerable effort may be required to collect fuelwood, especially by women and children, leaving little or no time for employment or school, respectively. Air pollution from inefficient stoves or fires will also cause human health problems. Similarly, charcoal production methods may be inefficient, entailing great effort under adverse working conditions and inefficient use of forest resources. In extreme cases in some parts of the world, charcoal production has also been associated with inhumane working conditions, child exploitation, and slavery.

The increased use of biofuels to mitigate climate change has increased focus on the total GHG savings that are achieved when transitioning from fossil fuels to biofuels. The total GHG emissions over the entire lifecycle, from biomass production, processing, and transport through to final conversion into energy should decrease. Emission savings compared to, for example, coal or gas in the United Kingdom was estimated to be above 90% for wood chips and above 70% for wood pellets (Bates et al. 2009).

10.5.2 Standards and Schemes for Sustainable Biomass

The need to create and apply adequate environmental and socio-economic sustainability standards becomes more pressing as woodfuel market share increases and international trading in biofuels grows. This has resulted in various initiatives to develop standards for sustainable biomass and bioenergy (van Dam et al. 2008), including the EU directive on the promotion of the use of energy from renewable sources (EC 2009), the work of the technical committee under the European Committee for Standardisation to elaborate a new standard for sustainably produced biomass for energy applications (CEN/TC-383, CEN 2009), the Roundtable for Sustainable Biofuels' global principles and criteria for sustainable biofuels production (RSB 2008), and the Green Gold Label and Laborelec certification systems for sustainable biomass (Control Union 2009, Laborelec 2009), and several others. These standards, schemes or systems are at various stages of development and address one or several operators along the bioenergy supply chain.

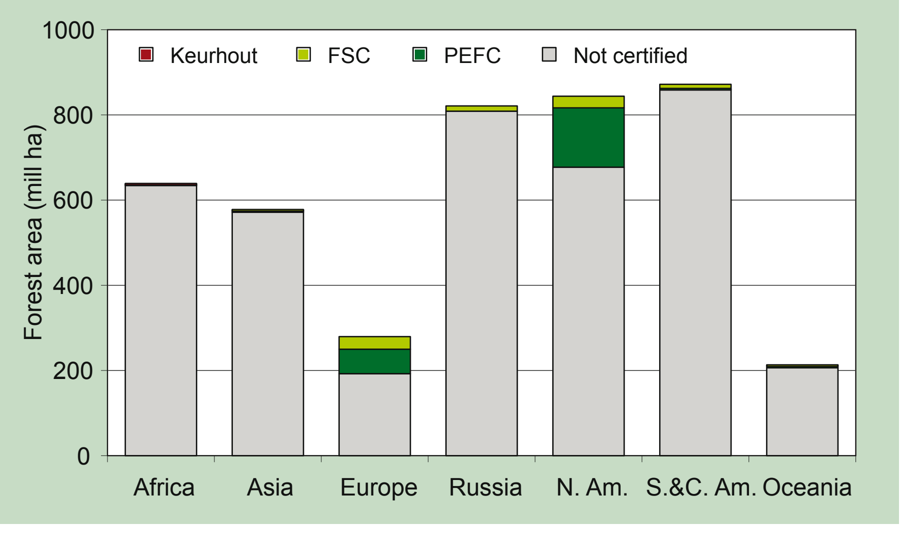

Figure 10.5 Area of non-certified forests in 2005 (FAO 2005), and certified forests in 2006 (ICFPA 2006) in different parts of the world.

The standards used by existing schemes typically ensure that the biomass was sustainably produced, that biomass with a sustainability claim is adequately controlled through the supply chain (chain of custody), or that sustainability requirements at the supply chain level (e.g., greenhouse gas emission savings and energy balances) are met (Figure 10.4). There is already a long tradition of standard-setting to ensure sustainable forest management and wood production at global, regional, and national levels; this creates a foundation for future verification of sustainable woodfuel production.

10.5.3 Frameworks for Sustainable Forest Management

Since concerns over destruction of tropical forests led to the first proposal for an international tropical timber agreement in 1976, significant efforts have been made to develop standards for sustainable forest management. These standards address the integrated production of a large range of goods from the forest and provide criteria for responsible forest management to ensure or improve ecosystem function, health and vitality; biological diversity; protection of soil and water; social and cultural values; human health, rights and participation in decisions affecting culture and livelihoods; and monitoring for adaptive management. The diversity of approaches to sustainable forest management in different parts of the world and different segments of society have led to development of a wide range of international processes, initiatives, and certification schemes to support sustainable forest management.

Nine international processes address certain regions or groups of countries in the world (FAO 2001). They encourage voluntary implementation at a policy level, and have thus influenced development of forest legislation around the world (Christy et al. 2007). Legislation may set minimum requirements for sustainable forest management within a country or jurisdiction, but voluntary forest certification schemes usually set higher sustainability standards, thus providing market verification for consumers wishing to support these higher standards. Certification takes place at the forest management unit level, using standards developed or adapted to national or sub-national conditions. There are two predominant global certification systems: the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). PEFC is an umbrella organisation that endorses previously independent national initiatives (e.g., Canadian Standards Association in Canada, the Sustainable Forestry Initiative in North America, and Cerflor in Brazil). Less than 25 million ha of forests were certified globally in 1998, but about 320 million ha (8.3% of the total global forest area) were certified by 2008; PEFC schemes accounted for about two-thirds of this area, and FSC accounted for the other third (UNECE/FAO 2009). By far the largest proportion of certified forests is in developed countries (Figure 10.5). A premise for the use of forest certification in global biomass and bioenergy certification is increased accessibility to certification processes in developing countries.

The increased importance of woodfuel as a forest product suggests that a revision of existing standards for sustainable forest management is required to ensure that they specifically address the unique management activities and impacts related to woodfuel production and harvesting. As described earlier, forest woodfuels often require more intensive management and can thus have incremental operational, biological, and silvicultural impacts above those for conventional roundwood production and harvesting. Especially the prevented GHG emissions vs. fossil fuels in energy production or traffic use is something new compared to sustainable roundwood production for forest industry purposes. The regular revision of standards is already an integrated part of forest certification schemes. Revisions are typically required every five years, thus supporting adaptive management. This allows the system to respond to changes in conditions and practices as those related to increased woodfuel production and harvesting. During regular revisions, some national standards under both PEFC and FSC have included indicators clearly aiming at sustainable woodfuel production practices (Stupak et al. 2009). Standards of some international processes may also develop to address woodfuels more comprehensively. The Ministerial Conferences of Protection of Forests in Europe (MCPFE) is, for example, currently assessing its tools for sustainable forest management in the light of new demands for woodfuels that have been produced in a sustainable manner (MCPFE 2009).

10.5.4 Future Systems for Certification of Woodfuels

One single global biomass or bioenergy certification system that covers all links of the bioenergy supply chain would be preferable from a standardisation perspective, and would increase the transparency and comparability of the sustainability of different biofuels; however, competition among systems is probably inherently positive. Energy policies and legislation have stimulated several market-based and governmental schemes for sustainable biomass and bioenergy to advance quickly. These systems rely partly on accreditation of existing certification systems, including those for sustainable forest management, that are likely to evolve to address sustainable forest woodfuel production more comprehensively than today. By sharing experiences gained through these systems, it may be possible to move towards more uniform and global standards for sustainable biomass and bioenergy, even if some differences probably must remain at detailed levels due to the great variety in forest management practices and in economic, social, and environmental conditions around the world.

10.6 Conclusions

The role of global forests as an energy source is increasing. The extent to which forests can bear more intensive utilisation, however, varies greatly between regions and countries. These regional differences have to be taken into consideration, when forest-based bioenergy systems are being developed. In the northern hemisphere, and particularly in many European countries, the accumulating growing stock and increased annual increment of forests because of improved management allows for more intensive use of forest biomass for biofuels for offsetting use of fossil fuels.

There are examples of destructive uses of forests for energy, leading to degradation of the resource and, in the longer run, hardship for local societies. However, this can be avoided or reversed through careful planning and implementation of sustainable forest management that addresses fuelwood harvesting, or by establishment of plantations for local domestic or even industrial fuelwood supply. Examples from Brazil and Senegal demonstrate that, with the commitment of policy makers and local people and industry, the impacts of unsustainable practices can be reversed with the introduction of new, sustainable systems.

The threats associated with wood fuels include the over-utilisation and depletion of forest ecosystems that jeopardise soil fertility, biodiversity, and greenhouse gas balances, and that can lead to erosion and water and air pollution. The working conditions and emissions from the combustion of wood fuels are also potential threats to occupational safety and to human health.

Forest-based energy production can reduce dependency on fossil fuels, and hence reduce greenhouse gas emissions from non-renewable sources; domestic production also improves energy security and contributes to energy price stability. It also can revitalise rural economies by providing work and income through production, harvesting, and conversion of biomass. With appropriate, modern conversion technologies, air quality in regions currently using woodfuels can be improved, especially in urban and suburban areas.

Forest energy policies have to be based on the principle of sustainable development, ensuring both economic and environmental longevity in the use of the resource, and taking into consideration the people affected by more intensive use of the forest. This is particularly important when large-scale land use change for establishment of energy plantations is planned.

Increasing demand for renewable energy has created new possibilities for forest-based livelihoods and income generation by adding a new commodity to the range of products that can be derived from forests.

All aspects of sustainable development – economic, ecological, and social – need to be included in the ongoing research and development work carried out by forest research organisations. Multidisciplinary research that is clearly linked to operational practices is essential for responding rapidly to increasing information needs regarding the role of forests in the global energy supply, and much remains to be done. Western countries have typically focused much of their recent research funding on biomass conversion technologies for creating energy, with less to forest operations and supply chain issues, and even less again to environmental sustainability issues. It is therefore essential that a balance be found so that adequate funding is used to build a solid foundation for all aspects of sustainability, thus ensuring that the benefits of forest bioenergy are truly optimised without compromising options for future generations.

Energy, forest, and regional policies should support the transfer of technology and best practices of sustainable use of wood for energy. Success stories on the establishment and management of economically, socially, and environmentally sound bioenergy systems at all levels, from single projects to national and even international scales, need to be documented and used to inform processes for the expansion of these systems into new regions. Here, multidisciplinary forest research with strong linkages to operational practises can play a key role. Linking research and practises maximises the applicability of new knowledge and accelerates the sustainable development of industries based on forest biomass resources.

The need for increased knowledge of all aspects of bioenergy has brought together a large number of new players in a research field that has until now been almost exclusively of interest to those involved in forest management and the forest industry. Engineering, energy, socio-economic, and environmental organisations and agencies with strong research capacity and versatile methodological backgrounds, and with connections to the energy and forestry industries, are challenging the leadership and relevance in this field of traditional forest research organisations. Forest policy is now strongly affected by megatrends in energy policies; recognising the rapid change in the research milieu and building on core strengths is the key for successful cooperation and networking between traditional forest research organisations and other fields of science. Forest research institutions must build their expertise and capacity based on a thorough analysis of the tasks, networks, and forums in which they decide to participate with other agencies. With strong expertise in forest ecosystems, operations, and products, forest research organisations can benefit from the ongoing wave of bioenergy and biofuels research, make a strong contribution to energy and climate change-related policies, support the transition of the forestry sector, and prepare to move forward on emerging issues – likely climate-change related – as the current suite of bioenergy-related issues are successfully overcome.

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