# Economic Sustainability of Biomass Feedstock Supply

This report was written by a group of researchers at the Finnish Forest Research Institute (METLA), with input from colleagues at the University of Toronto and the University of Copenhagen. It was written as part of ongoing work with IEA Bioenergy Task 43 to improve all aspects of the bioenergy supply chain.

IEA Bioenergy

IEA BIOENERGY: Task 43: TR2013:01

# ECONOMIC SUSTAINABILITY OF BIOMASS FEEDSTOCK SUPPLY

**Lead Authors: Tanja Ikonen (Finnish Forest Research Institute, Finland), Antti Asikainen (Finnish Forest Research Institute, Finland)**

**Contributing Authors: Robert Prinz (Finnish Forest Research Institute, Finland), Inge Stupak (University of Copenhagen, Denmark), Tat Smith (University of Toronto, Canada), Dominik Röser (FPinnovations, Canada)**

## Technical report

## KEY MESSAGES

The economic dimension of sustainability is often overlooked in discussions of forest-based biomass, biofuel and bioenergy sustainability. The purpose of this report was to address key contributing factors toward economic sustainability that can ensure more viable bioenergy development and use, such as increasing operational efficiency and integration into traditional supply chains. It was concluded that economic, environmental and social dimensions of sustainability are highly interconnected and that bioenergy value chains must generate profits also for biomass suppliers in order to create sustainable feedstock supplies for growing biomass markets.

**Disclaimer**: Whilst the information in this publication is derived from reliable sources and reasonable care has been taken in the compilation, IEA Bioenergy and the authors of the publication cannot make any representation or warranty, express or implied, regarding the verity, accuracy, adequacy or completeness of the information contained herein. IEA Bioenergy and the authors do not accept any liability towards the readers and users of the publication for any inaccuracy, error, or omission, regardless of the cause, or any damages resulting there from. In no event shall IEA Bioenergy or the authors have any liability for lost profits and/or indirect, special, punitive, or consequential damages.

**Cover Picture:** © Glosco Wood Inc. and Sally Krigstin

## CONTENTS

# 1.0 INTRODUCTION

Climate change mitigation efforts, the increasing scarcity and cost of fossil fuels, and concerns over energy security have brought forests and other sources of bioenergy into focus in the global energy discussion. Accordingly, several countries have set targets to increase the share of renewable energy sources as a climate change mitigation option (Asikainen et al. 2010). For example, EU countries are required to produce 20% of their energy by 2020 from renewable sources, including bioenergy, and it is anticipated that a large share of this will come from forest-based biomass. The Renewable Energy Directive (RED) promotes the use of forest biomass for energy purposes (European Commission 2008), but meeting the EU`s 2020 targets calls for more measures and strategies that enhance the effectiveness and profitability of biomass feedstock supply.

In many countries, such as Finland, U.S. and Canada, there is a need to restructure and diversify the forestry sector. In the 2000s, the price of many pulp and paper products decreased dramatically, whereas the price of energy products increased. In the U.S. industrial sector, however, the amount of wood energy produced was driven mainly by the pulp and paper industry demonstrating the linkages between the different sectors (Aguilar et al. 2011 a and b). 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 (Hetemäki 2008).

The international trade of bioenergy is an important part in a global forestry and energy sector, especially in Europe, North America and Southeast Asia. The use and trade of wood-based fuel is increasing, mainly driven by policies and commercial driving forces (Hillring 2006). In addition, Junginger et al. (2008) conclude that sustainable production of biomass will have an increased influence on the international bioenergy trade.

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 feedstocks and market prices of energy products are changing all the time, and the cost of fossil fuels, especially, show large variations.

In recent years, more and more attention has focused on the economic viability of biomass producing companies and the overall economic sustainability of forest biomass production. The share of solid fuel feedstocks, such as biomass, in the operation costs of a typical energy plant is often 60-80% (Heiskanen & Flyktman 2005). Therefore, the competitiveness of biomass-based energy generation strongly depends on the cost and quality of feedstock supply. Nonetheless, the economic dimension of bioenergy sustainability has not been addressed to the extent that the ecological and social dimensions have been in recent sustainability discussions. To address this disparity, this paper focuses on the dimensions and levels of economic sustainability and the factors affecting the economic outcome of forest biomass supply for energy production.

## 2.0 SUSTAINABILITY CRITERIA OF BIOMASS FEEDSTOCK SUPPLY

*Sustainable development* describes an approach to planning and decision-making that aims at achieving long-term and lasting positive impacts on environment, society and economy. The World Commission on Sustainable Development report in 1987 and the United Nations Conference on Environment and Development in 1992 both contributed toward the current understanding of *sustainability*, which has the three dimensions: *economic*, *environmental* and *social* (Figure 1). Cultural values are also very important to consider, especially in communities characterized by high cultural, ethnic and racial diversity. The major elements of sustainability are characterized by a high degree of interaction and there is often much overlap between them.

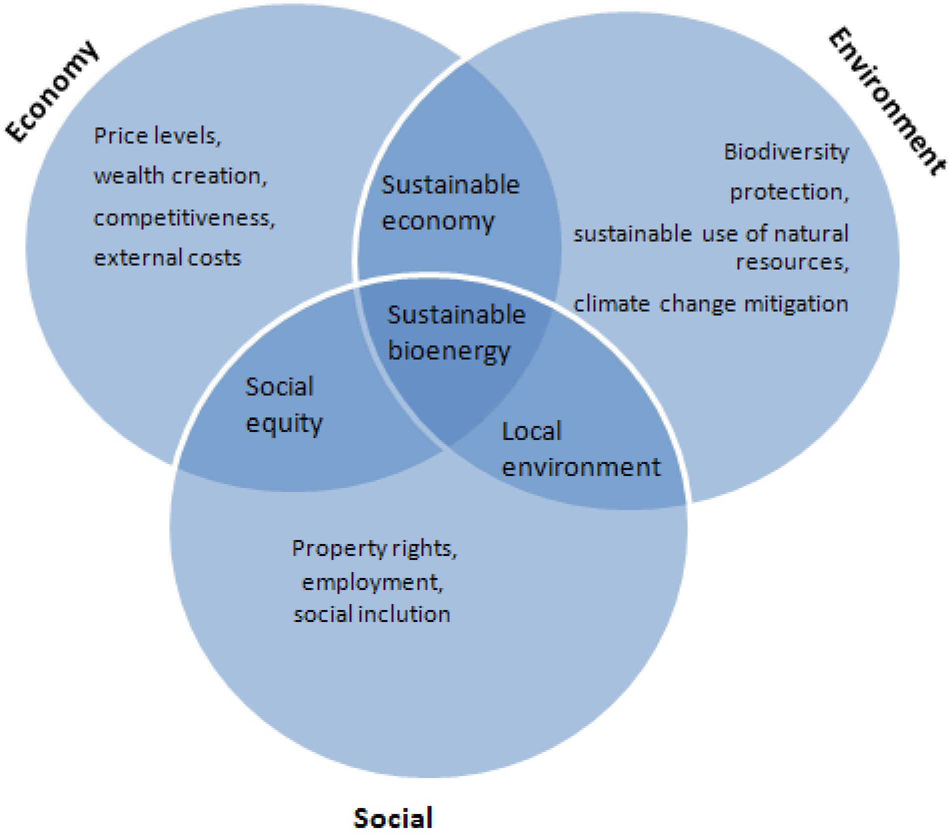


**Figure 1**. Dimensions of bioenergy sustainability
(World Commission on Environment and Development 1987).

Sustainability can be understood in different ways, depending on how the three dimensions of sustainability interact with each other and how resources and capital are managed (Hill 2011).

- *Strong sustainability* requires that each type of natural resource or capital be preserved independently. This implies that the different types of capital and resources may complement, but not replace each other. For example, economic benefits cannot substitute for a loss of biodiversity or other natural resources.
- *Weak sustainability* means that the total capital of the system is preserved, but economic, environmental and social capital can be substituted for one another (Hill 2011, Asikainen 2011). Weak sustainability in the forest sector may imply that if a forest is harvested and there is damage which reduces the environmental capital, the system can still be considered sustainable if there is an increase in other forms of social or economic capital (e.g. increased employment or wealth creation), and the sum of all changes is positive (Lunnan et al. 2008).
- *Sensible sustainability* means that the total capital is preserved, but there are critical limits for each type of capital below which the capital must not fall (Asikainen 2011). These critical limits can be defined for both individual capital and for ecosystems, but defining where these limits lie can be problematic (Lunnan et al. 2008, Hill 2011).

In the forest sector, the first concept of sustainability was developed in the 18th and 19th centuries in terms of sustained yield and the model of the normal forest (Lunnan et al. 2008). The contemporary view of sustainable forestry and forest management recognizes that in addition to timber and biomass products, forests provide many social, environmental and other economic benefits as well (Freer-Smith 2007).

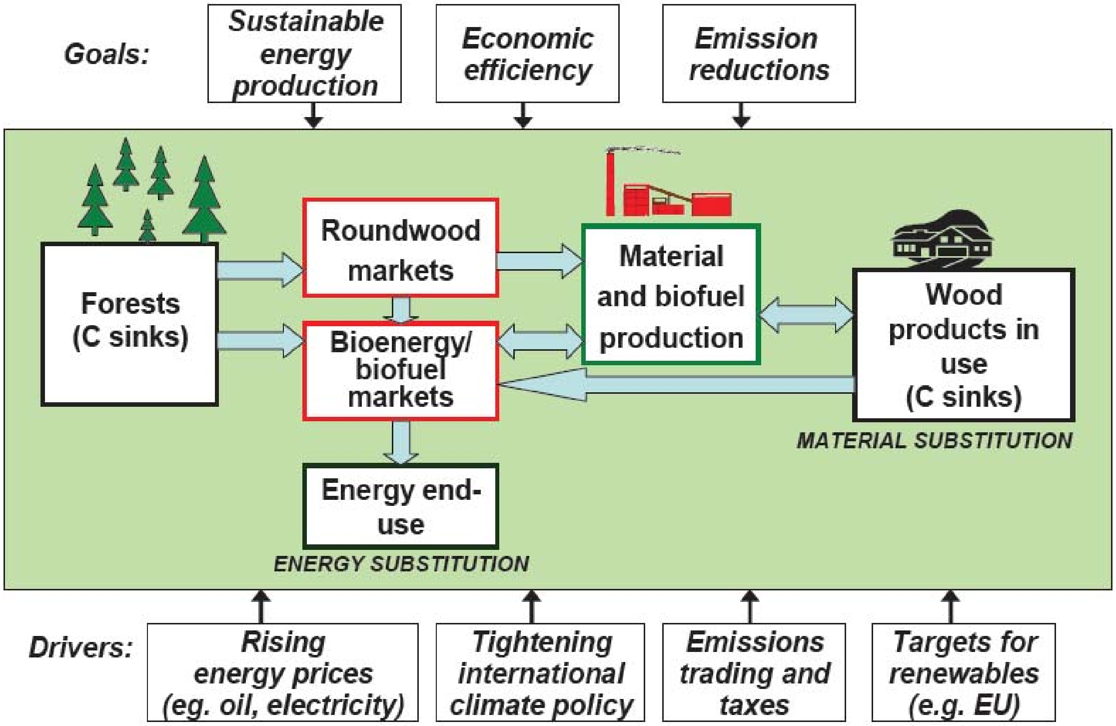


**Figure 2**. Sustainable bioenergy production (Pingoud & Forsstöm 2009).

International and national drivers and energy policies advance sustainable bioenergy use and set the goals for climate change mitigation and energy use (Figure 2). The recent drivers of woody biomass use and bioenergy production worldwide include energy supply and security, greenhouse gas mitigation and economic development (FAO 2010). For biomass supply chains to be sustainable, issues concerning emission reduction, economic efficiency and sustainable energy production have to be considered. Sustainability of the feedstock supply chain requires that benefits from forest biomass obtained in the present do not compromise the opportunities for future generations to meet their needs (Lunnan et al. 2008).

Sustainable sources of woody biomass may include natural and managed forests, dedicated energy crops and non-forest trees. By-products and wood waste from the forest industry may be another sustainable source of woody biomass for energy (FAO 2010, Lunnan et al. 2008). The ability to grow successive rotations of timber without productivity losses contributes to the profitability of forestry and sustainability (Freer-Smith 2007). Sustainable forest management is a pivotal element of sustainable energy production and it is critical that possible adverse effects, such as biodiversity losses do not outweigh the benefits of the bioenergy production and use. *Bioenergy production is considered sustainable if biomass utilization levels do not exceed growth over time.* This ensures that forests act as a carbon sink, which may cancel out $CO_2$ emission from wood-based energy production (Figure 2).

Sustainability can be assessed at a local, national or international level. At the local level, biomass production and harvesting improves local employment and increases tax revenues to communities (Hubbard et al. 2007). Forest biomass production contributes to economic development, particularly in low-income countries, by supporting local economies through biomass harvesting, employment, and greenhouse gas credits (FAO 2010). Nationally, it also helps to improve energy supply security. On a global scale, substituting fossil fuels with biomass helps by reducing $CO_2$-emissions and reducing the use of non-renewable fossil fuels.

There are also a number of potentially adverse effects that must be taken into consideration in order for biomass production, supply and utilization to be considered sustainable (Lattimore et al. 2009, FAO 2010). Main concerns relate to maintaining long-term soil fertility, managing watersheds, maintaining biodiversity, and mitigating climate change (Asikainen 2011). Biodiversity concerns arise at both species and landscape levels (Lunnan et al. 2008). Concepts of social and environmental sustainability and the role of 'governance' such as voluntary certification systems are discussed further in sections 6-8.

## 3.0 DEFINITIONS OF ECONOMIC SUSTAINABILITY

Economic sustainability in this context is concerned with long-term stability and balance. The activity is considered economically sustainable when production or activity delivers more benefit than cost over its complete life cycle, and all environmental, social, and economic factors are taken into account (Hardisty 2010). Companies must ensure that while operating and pursuing profits in the short term, business operations are not causing harm to the local and global environment over the long term. Operating in short quarter-based timescales, companies cannot always guarantee proper decision-making, economically sustainable operations and long-term profitability. Strategic planning in 2-5 year periods and stability in business operations are required for creating local welfare and prosperity. In sustainability assessments, business operations and profitability are reviewed in 5-15 year periods (Doane & MacGillivray 2001).

The objective of economically sustainable business production is not only to obtain long-term profitability, but also to produce positive external effects and benefits to society and the environment. Companies are able to make positive contributions to their local community, broader society and even planet as a whole when they act in a sustainable way (Doane & MacGillivray 2001). Economic sustainability is thus strongly connected to other dimensions of sustainability, and is defined in the context of social and environmental impacts. Using this principle, the economic benefits of bioenergy should be maximized, and long-term economic viability should be maintained (FAO 2010).

Economic sustainability can be analyzed either through internal functions of the company or by the external effects on society and environment (Table 1.). From the internal point of view, the financial performance of a company and capability to manage assets are the most important factors leading to economic sustainability. Analysis of the external implications of economic sustainability management focuses on the company`s influence on the wider economy and how the company manages social and environmental impacts (Table 1.). In a survey conducted by Buchholz et al. (2009), microeconomic sustainability was considered the most important economic criterion among bioenergy experts. Microeconomic sustainability implies the company`s ability to maintain long-term profitability.

In most scenarios and calculations, measures of microeconomic sustainability are presented in monetary terms through which the added value can be analyzed (Table 1). Gross profit and gross profit margin, production costs and return on investment (ROI) are common parameters used. Macroeconomic factors such as employment effects, other social effects and climate change mitigation can also be examined. In this report, the main focus is on costs, as costs are more relevant than prices when the overall attractiveness of biomass is being reviewed. Prices tend to be local, hard to predict and therefore, hard to use as a basis for cost-competitiveness analysis.

In addition to positive external effects, external costs should be included in the overall economic sustainability assessment. External costs are planned or unplanned environmental and social impacts that are the result of a process or activity despite attempts at mitigation (Hardisty 2010). External costs and economic sustainability are re-enforced by public policies and subsidies, such as in the case of agricultural production or fossil fuels. In fossil fuel production, external costs are especially high, which makes renewable energy economically more sustainable. Even though fossil fuels are cheaply available in the market, high $CO_2$ emissions, other air pollutants during production process and other significant life-cycle external costs (including the mining footprint) severely disadvantages fossil fuels and especially coal compared to other forms of energy (Hardisty 2010).

**Table 1.** Measures of economic sustainability and added value generation (adapted from Doane & MacGillivray 2001)

| Criteria | Indicator | Added value |
|---|---|---|
| Profitability | Level of profit<br>Profit margin<br>Production costs | Benefits to the local and national economy<br>Macroeconomic sustainability<br>Microeconomic sustainability |
| Investments and investment level | Fixed costs<br>Return on Investment (ROI)<br>Number of new investments made | Economic growth<br>Macroeconomic sustainability<br>Microeconomic sustainability |
| Employment | Annual wages (€)<br>Number of people employed to the sector<br>Number of jobs available<br>Quality of employment | Welfare<br>Economic growth<br>Macroeconomic sustainability |

| | | |
|---|---|---|
| Outsourcing and supply chain management | Raw material/fuel costs<br>Procurement costs<br>Outsourcing costs | Improved profitability<br>Microeconomic sustainability |
| Environmental management and policies | Price of emission allowance<br>Costs of emission trade<br>Subsidy levels and mechanisms | Decrease in $CO_2$ emissions<br>Environmental sustainability<br>Microeconomic sustainability |

Forest biomass is a local fuel, which competes on global markets. Supply chain efficiency and costs are critical to consider when evaluating the economic sustainability of forest biomass supply. Costs related to silviculture and managing forest resources are not included in this economical assessment.

Bioenergy supply chains generally consist of four interrelated phases: feedstock production, which includes procurement and logistics of the feedstock, feedstock-to-bioenergy conversion, and bioenergy distribution. The end-use (e.g. energy production) can also be included into the value chain analysis (Figure 3).

**Figure 3.** Biomass feedstock supply value chain (FAO 2010).

The main phases in the biomass supply chain are as follows; identifying the potential biomass resources and purchasing of the woody biomass, harvesting, forwarding to the roadside, comminution, long-distance transport to the plant and receiving and handling the biomass at the plant site. The main factors determining the cost of forest biomass are long-distance transportation to the plant or terminal, moisture content of the fuel and stumpage price of the wood. The cost structure is also dependent on energy market fluctuations and labour and machine costs throughout the supply chain. In Scandinavian countries, the location of the comminuting phase in the whole supply chain affects the total costs of feedstock supply (Fagernäs et al. 2006).

Economic sustainability of forest biomass energy has four major criteria:

- beneficial use,
- economic viability,
- economic equity, and
- property rights and landowner expectations (FAO 2010).

Under these criteria, several indicators can be measured (Table 2). These include production costs, cost-competitiveness of woody biomass as compared to competing energy resources, and employment effects of bioenergy production, among others.

**Table 2**. Sustainability of wood fuels and bioenergy (FAO 2010).

| Criterion | Indicators |
|---|---|
| **Beneficial use** | Direct and indirect benefits outweigh the cost<br>Efficiency in supply chain<br>Most beneficial use of woody biomass |
| **Economical viability** | Cost-competitiveness of wood fuels and bioenergy as compared to competitive energy recourses<br>Profitability of bioenergy production |
| **Economic equity** | Fair distribution of economic benefits among all stakeholders along the woodfuel supply chain<br>Added value in supply chain<br>Accessibility and affordability of wood fuels to local residents<br>Employment opportunities |
| **Prosperity and property rights** | Institutional requirements to avoid illegal harvesting and overexploitation of forest |

To ensure that the key issues related to bioenergy production and feedstock supply are fully recognized and addressed, they need to be analyzed within a rational framework. The capacity to apply criteria and indicator schemes to an operation varies according to the scale, location and a range of other factors pertaining to the operation in question, e.g. availability and accessibility of information and cost of production (FAO 2010).

## 4.0 DIMENSIONS OF ECONOMIC SUSTAINABILITY

The amount of bioenergy that consumers are demanding in the market and the fuel prices they are willing to pay define the limits of economic sustainability for biomass feedstock supply. Several internal and external factors affect economic sustainability. Several of these are examined in this section to illustrate their impacts on the economic sustainability of feedstock supply.

The price of *competing fuels* will set a limit on the willingness of consumers to pay for biomass. Prices can be affected by different *support mechanisms* for biomass such as feed-in tariffs, subsidies and increased $CO_2$ taxes set for competing (often fossil) fuels.

The monetary inputs described, such as *investment costs* of machinery and direct operating and *labour costs* are the defining factors affecting profitability of supply chains. In the long term, machine technology, logistics and fuel *storage management* can be developed to reduce investment costs and capital tied up in storage. In addition, *seasonal variations* in demand affect the profitability of supply chains and the utilization rate of machines, which can have a large impact especially in smaller companies.

## 4.1 Impacts of Emission Trade on Feedstock Supply in the EU

Global $CO_2$ emissions from fossil fuels have increased dramatically in recent years. During 2009, the economic recession in developed countries decreased $CO_2$ emissions, but in 2010 emissions began to increase again through growing consumption of fossil fuels in some of the larger developing countries (Figure 4). The combustion of coal accounts for 43% of global $CO_2$ emissions, 37% of emissions were from oil and 20% from gas (IEA 2011, BP Statistical review 2011).

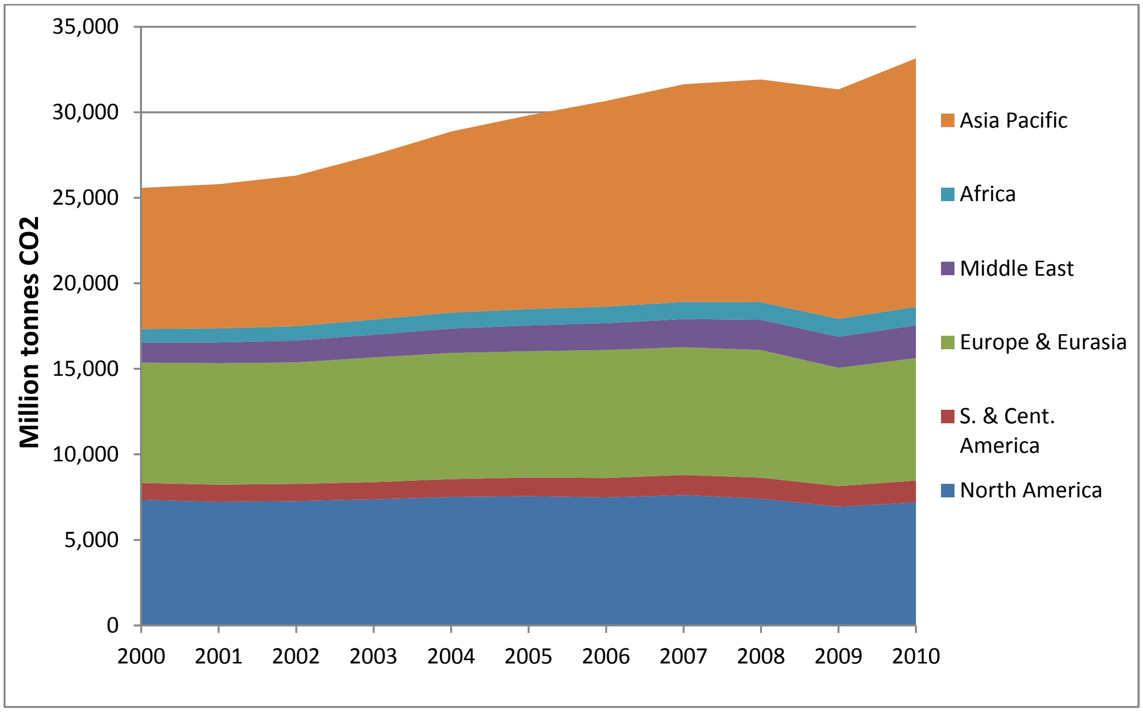


**Figure 4.** Global $CO_2$ emissions increased 5.8% from 2009 to 2010 (BP Statistical review 2011).

Various EU policies, directives and regulations are aimed at ensuring a sustainable energy production in Europe and diminishing the dependence on imported fuels. In the Green Paper the European Commission sought views on the proposed objective of 20% renewable energy shares (RES) toward the EU`s gross inland energy consumption by 2020 (Fagernäs et al. 2006).

The Intergovernmental Panel on Climate Change (IPCC) is also analyzing global greenhouse gas emission adaptation and mitigation options. Key mitigation technologies and practices for forest sector include the use of bioenergy when replacing fossil fuels. Since bioenergy production and use is considered to be nearly carbon neutral within the emission-trading scheme, energy producers` ability to buy biomass has increased and, consequently, increased the demand for woody biomass.

In economic sustainability assessments, the effect of emission trading is analyzed by how it benefits society. Emission trading systems encourage large heat and power plants to produce energy with $CO_2$ neutral fuels when it is more cost efficient than fossil fuels. Whether emission trading is effective in increasing the use of bioenergy depends on several features of the scheme design, including the carbon price and the permit allocation method (Tuerk et al. 2011).

The emission trading system does not  directly affect woodfuel prices. Instead, emission trade works as a support mechanism, which can enhance the competitiveness of woody biomass by increasing the plants` paying capability for wood fuels as compared to fossil fuels. During recent years, the EU`s efforts toward $CO_2$-emission mitigation, the aim to utilize regionally available fuels as well as increasing costs for fossil fuels have  increased support globally for wood combustion (Brunner et al. 2012). In Europe, wood-based bioenergy is subsidized in a way which effectively out-competes fossil fuels (Olsson 2012). Fossil fuels are typically used in peak load boilers, and therefore fossil fuels and wood-based bioenergy are rarely direct substitutes. This means also that emission trade mechanism, which affects fuel cost in the production phase, has no significant affect on wood fuel and chip prices (Olsson 2012). In some cases, emission trading can distort local markets by reducing the availability of woody biomass for plants beyond the emission trading system and wood procurement networks, especially when the $CO_2$ prices peak (Karttunen et al. 2008).

As the $CO_2$ price increases, the variable costs for both gas and coal-based power plants rise because an emission allowance is needed for each unit of $CO_2$ emitted (Tuerk et al. 2011). As a result, the wood-paying ability of energy producers increases and the gate price of forest biomass and chips rises (Fagernäs et al. 2006). Consequently, the prices of fuel chips has been following the price of $CO_2$ allowances, and in general prices have increased during past 4-5 years at the same pace (Figure 5).

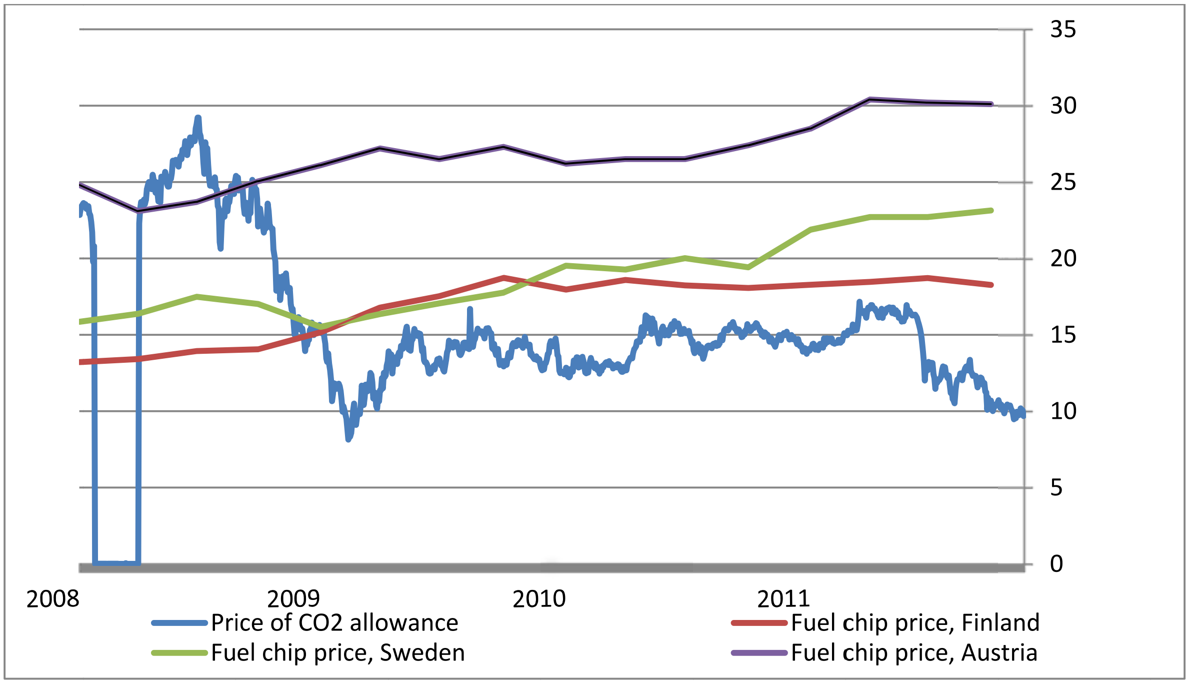


**Figure 5.** $CO_2$ allowance prices and fuel chip prices in Europe, €/MWh (Statistics Finland, Swedish Energy Agency, C.A.R.M.E.N, ICE 2011).

The price of $CO_2$ allowances collapsed in 2007-2008 when the first phase of the emission trade ended. At the same time, the growth rate of wood-based primary energy production stagnated in Scandinavian countries in particular. In Finland, the production of wood-based fuels reduced by almost 14%, especially in large energy intensive plants over 20 MW (Figure 6). This was because those facilities maximized the use of fossil fuels in their fuel mix in the end of 2007 to save all $CO_2$ neutral fuels for the next Kyoto period. It was believed that $CO_2$ allowance prices would rapidly rise to over 20 €/tonne $CO_{2eq}$ in the beginning of the new emission trade period. In 2008, the $CO_2$ allowance prices rose and large plants maximized wood fuel use, which was directly reflected in fuel chip prices. Accordingly, wood chip prices showed a rising trend during 2008-2009 (Figure 5). Since that time, the trend has stabilized.

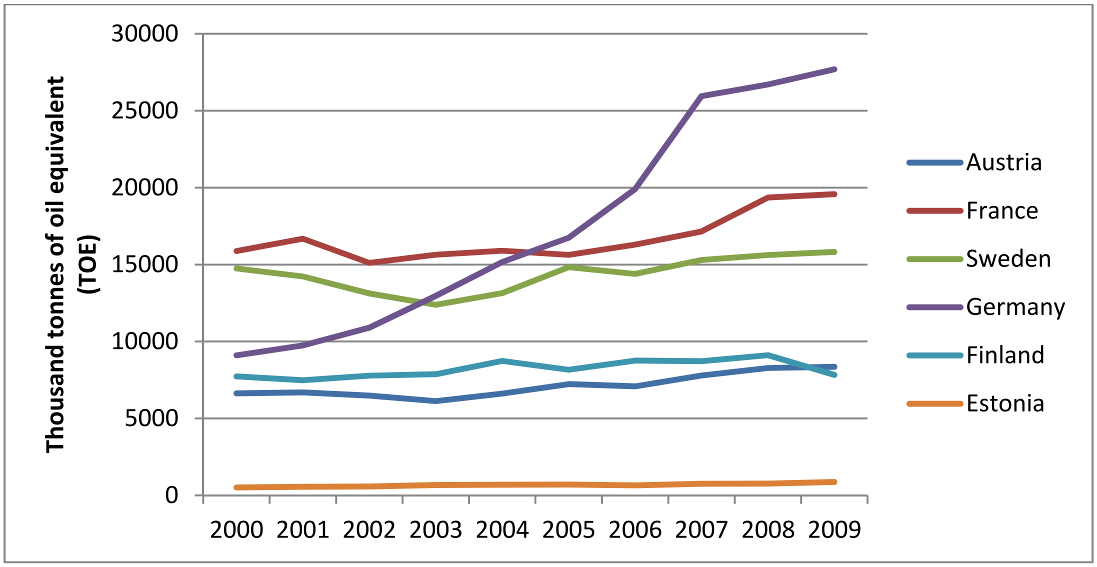


**Figure 6.** Primary production of renewable energy in selected countries (Eurostat 2011).

Simultaneously, small plants (<20 MW) in Finland began to use more wood, but could not create enough demand to keep the supply chain running smoothly. Smaller plants tried to use peat as much as possible, which caused problems in many facilities because their combustion technology were not designed for large proportions of peat. High volatility in demand caused an inefficient use of supply capacity.

In general, both supply and demand of forest biomass are inelastic. This means that in a certain region over a certain time period, plants consume a specific amount of biomass, which has to be supplied by the local producers. In theory, the emission trading mechanism increases the demand elasticity of forest biomass especially in large energy facilities using mixed fuels because it raises the cost of using fossil fuels relative to wood. The demand shifts from renewable sources to fossil fuels when $CO_2$ prices are low and back into renewable, forest biomass when prices are high. In practice, this is only an option for plants that are able to take a range of fuels. Decisions regarding a short-term fuel switch to biomass are based on the so-called "Short Run Marginal Costs (SRMC)". When there is a carbon price, $CO_2$ costs, which depend on the fuel specific $CO_2$ emissions as well as the $CO_2$ price have to be added to the SRMC. With no carbon price, coal has the lowest SRMC of all options (Tuerk et al. 2011).

On the supply side, price increases and additional market supply are not necessarily connected. Supply feedstock chains cannot react to demand fluctuations quite as fast as the demand changes. Recently, $CO_2$ prices have been descending, which could decrease biomass demand in plants using multiple fuels. This would be reflected in an increase in regional supply of forest biomass for energy use.

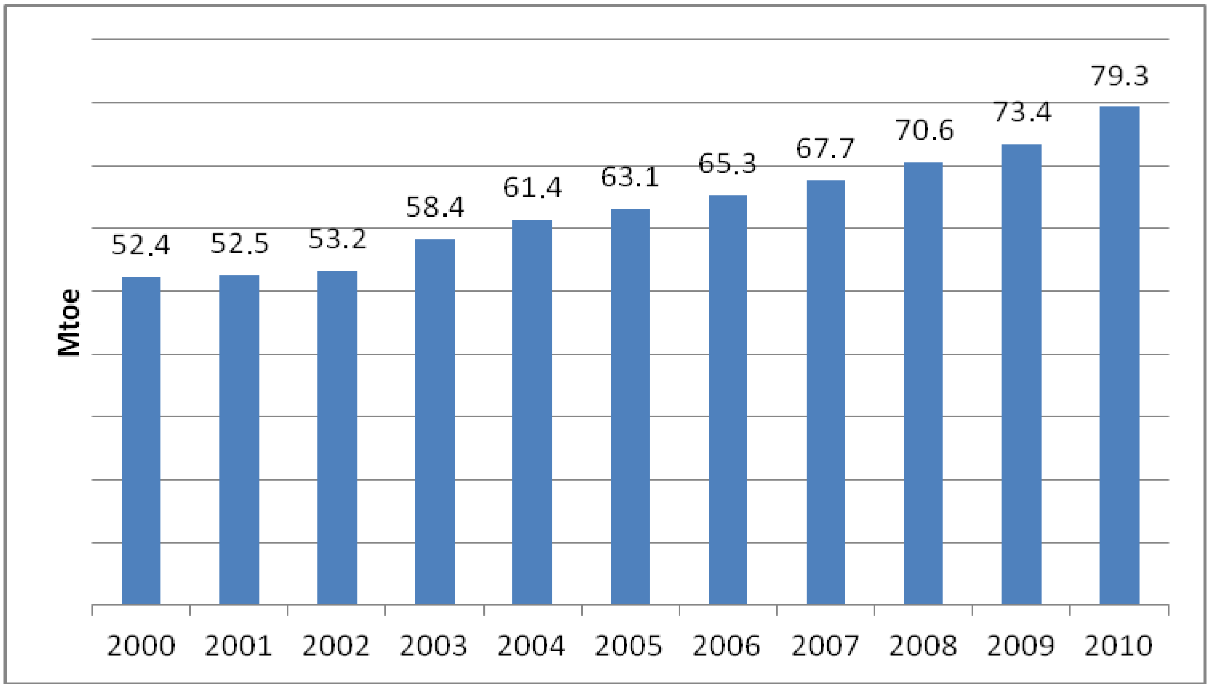


**Figure 7.** Solid biomass primary energy production growth in EU in 2000-2010 (Eurostat, EurObserv`ER 2011).

Use of woody biomass in energy production has continued to grow, driven mainly by EU`s 20% renewable target (Figure 7). During the past ten years, the use of woody biomass has increased mainly due to CHP installations in Nordic countries and Germany and Austria somewhat as well (Fagernäs et al. 2006). In these countries, the majority of solid biomass used is from forests. In North America, woody biomass accounts for about 3% of USA`s and 6% of Canada`s energy production (UNECE 2011). Canada and USA are major suppliers of woody biomass feedstock, primarily pellets, to the EU. The highest proportion of energy produced from woody biomass is in the Nordic countries and Austria, where 11-18% of total primary energy is supplied from woody biomass (Figure 8).

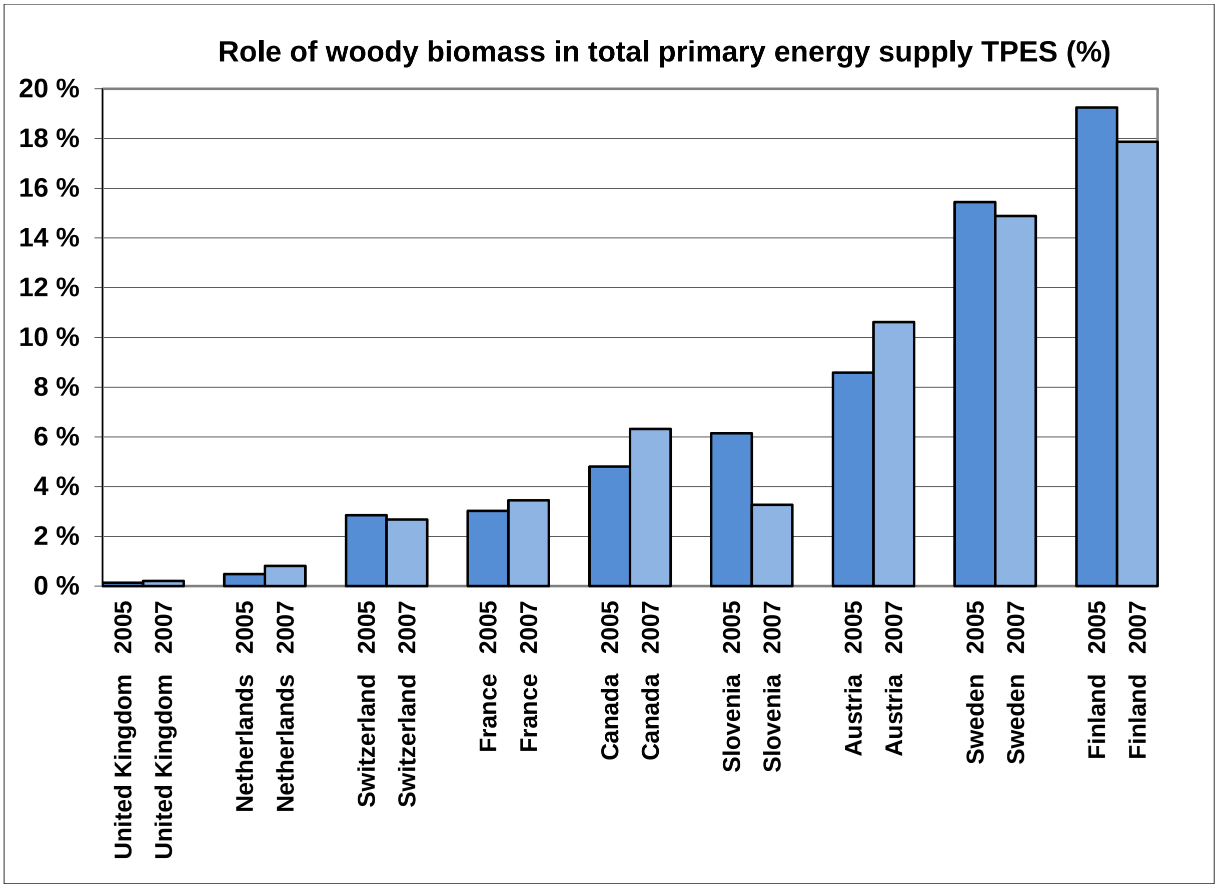


**Figure 8.** Share of woody biomass in primary energy supply (Aquilar et al. 2011a).

Scenario studies show that goals set in the EU for wood-based energy and material use would lead to 47 million m$^3$ increased wood demand in 2020 and that this is more than forests in the region are able to supply (Asikainen 2011). In the Scandinavian region, the potential demand has clearly exceeded the realized regional supply and competition for biomass resources has elevated the fuel prices as a result of municipal heating plants competing with traditional forest industry (Ranta et al. 2007). Large heat and power facilities are able to secure woody biomass with procurement contracts, which reduces the amount of available energy wood for small and medium size energy facilities in the sector (ET Bioenergy 2005).

## 4.2 Competing Fuels – World Markets and Economic Cycles

In order to be competitive, energy produced from forest biomass must be as cheap as or cheaper than energy produced from competing fuels. The profitability of different alternatives must be assessed for the entire life expectancy of the energy production plant. Overall profitability and costs can vary a great deal depending on local conditions. Fuel demand and costs (€/MWh) depend on heating value, operational hours and efficiency. Biomass-based production is usually more costly to build, but cheaper to operate than a fossil fuel based plant (Alakangas & Flyktman 2001). Plants designed for wet biomass are usually more expensive than plants using dry biomass. On the other hand, dry biomass is typically more expensive than wet biomass.

Currently, wood-based energy production is not cost-competitive with fossil fuel-based energy production; carbon credits and subsidy measures are required to overcome the cost advantage of coal (Kumar et al. 2003). With current fossil fuel prices and production technologies used to make wood-based bioenergy, supply chains and conversion technologies require further research, development and optimization.

However, the costs in these calculations are constantly changing; in particular the cost of fossil fuels show large variation (Lunnan et al. 2008). Changes in the world economy reflect strongly in global energy consumption and energy prices. Oil remains the world`s most commonly used fuel, at 33.6% of global energy consumption (Figure 9). Coal consumption grew by 7.6% in 2011 and coal now accounts for 29.6% of global energy consumption. (BP Statistical review 2011) The 2009 recession was also reflected in fossil fuel markets and consumption decreased temporarily (Figure 9).

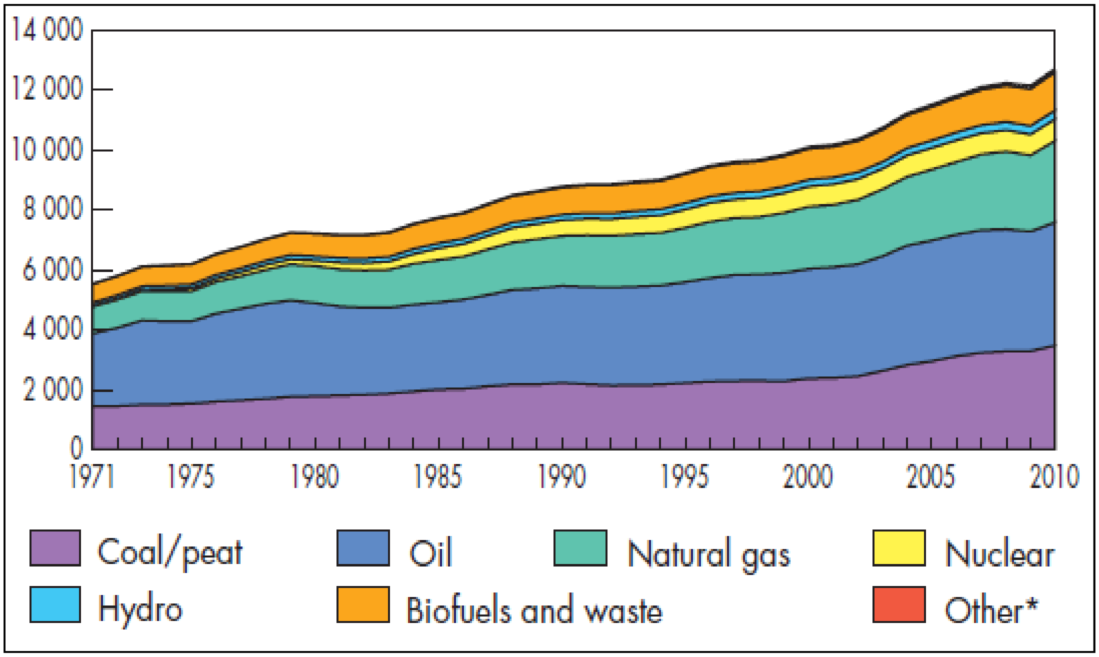


**Figure 9.** World primary energy production (Mtoe). Oil is the dominant fuel in the world market for all regions except Europe and Eurasia, where natural gas is the leading fuel (IEA 2012).

In 2010, the global energy market grew more rapidly than the economy for a second consecutive year and global energy consumption realized the strongest growth since 1973 (BP Statistical review 2011). Fossil fuel consumption increased in 2010 in all regions, especially in Asia. The Asia Pacific region lead in global energy consumption, accounting for 38.1% of total energy consumed. China`s share of global energy consumption is the world largest at 20.3%. China`s energy consumption is mainly dependant on coal; in 2010, China accounted for two-thirds of global growth in coal consumption and consumed 48.2% of world`s coal (BP Statistical review 2011).

In 2011, the tsunami in Japan and unrest in the Middle East disturbed fossil fuel production and trade flows, which caused rising fuel prices. Oil prices have risen globally (Figure 10) while the natural gas and coal prices have varied by region. Higher crude oil prices feed into higher energy prices and increase costs in energy production for companies, which can enhance the cost-competitiveness of wood fuels compared to fossil energy sources.

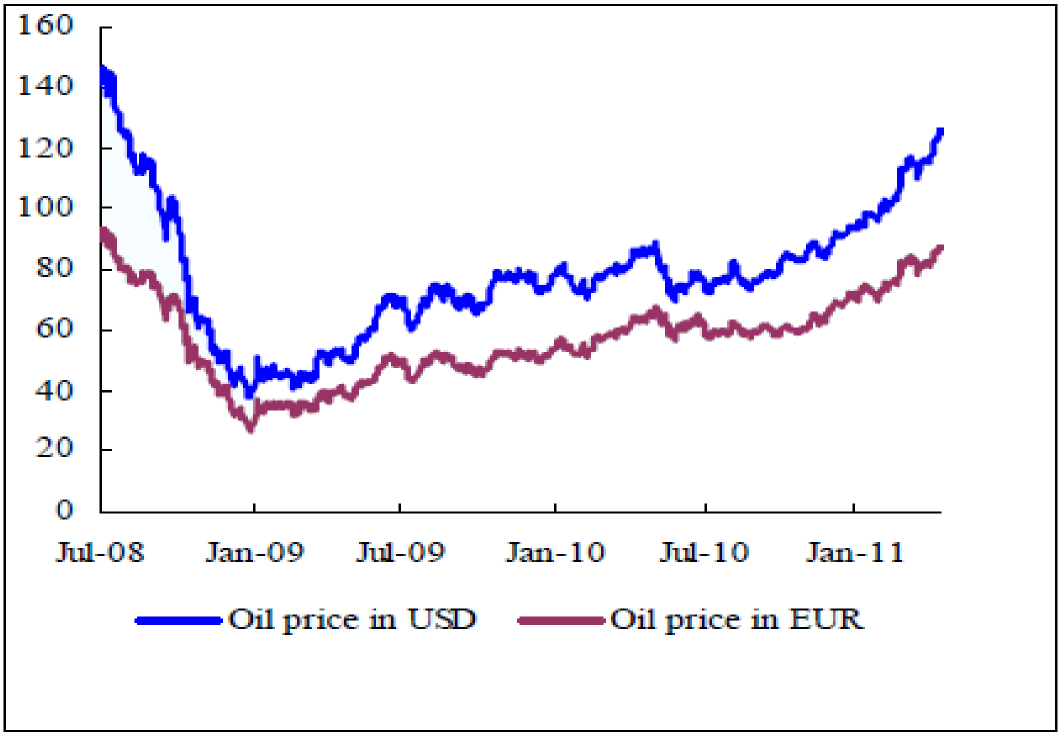
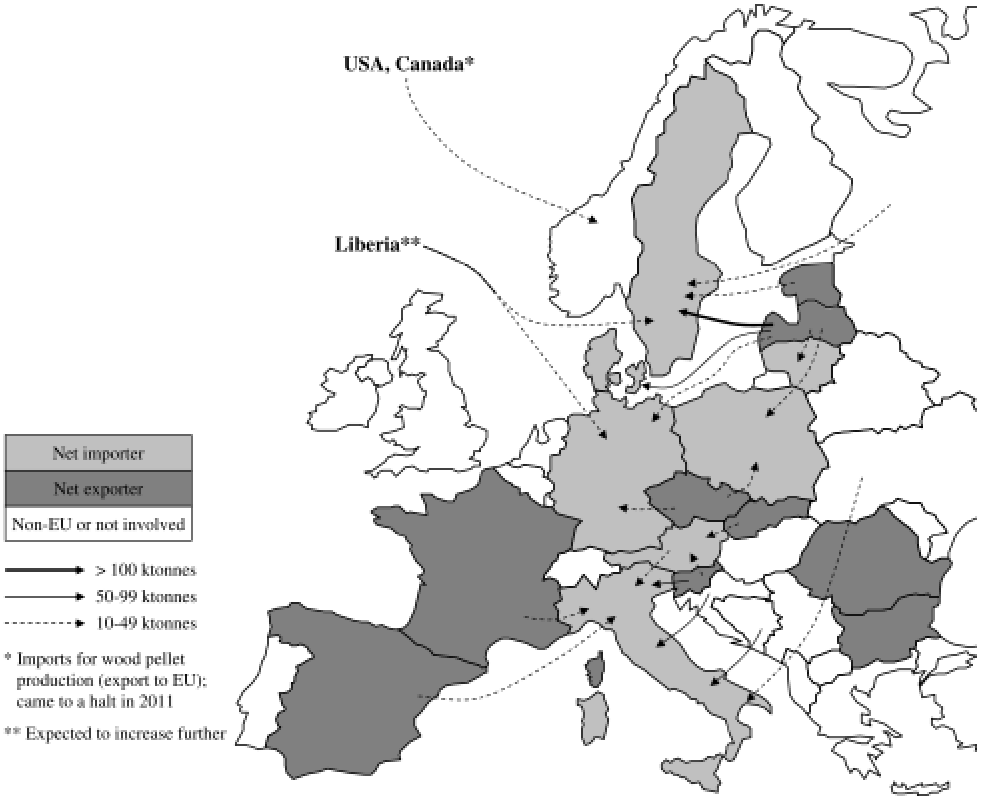


**Figure 10.** Crude oil price development 2008-2011, dollars. (European Economic Forecast 2011).

With limited substitution possibilities in the short run, the oil-price increase has an immediate negative effect on wealth and income creation (European Economic Forecast 2011). By the end of 2012, the world economy is heading towards yet another period of slow growth, which might affect the fossil fuel consumption and prices in the future. Although the price of woody biomass isn`t dependent on world economic cycles, demand for energy and purchasing capability of the energy producing plants is. Although fossil fuel prices are an important driver of bioenergy development, unrefined wood markets are still mainly national in operation and the influence of the forest products industry seems to be more important than oil price fluctuations (Olsson 2012, Kranzl et al. 2012). The connection between oil prices and wood fuel prices is not very strong, especially in Scandinavian countries (Olsson 2012). However, oil prices are likely to influence wood fuel markets over the long term. Higher oil prices mean greater incentives for energy consumers and producers to invest in other forms of energy, which means a long-run increase in the demand for wood fuels (Olsson 2012). If $CO_2$ taxes and fossil fuel prices continue to rise, the demand for woody biomass is likely to grow as investments in biomass-based energy production become more cost-competitive.

International bioenergy trade plays an important role within the global energy market. The global solid and liquid biomass trade for energy has increased in the 2000s. The total trade volume of bioenergy products such as wood chips for energy, wood pellets, bioethanol and biodiesel has increased substantially between 2000 and 2010. For example, the solid biomass trade exceeded 300 PJ in that same time period (Junginger et al. 2012). Kranzl et al. (2012) predict a strong increase in total international biomass trade between 2010 and 2050 by a factor of 20 to 90, depending on trade barriers and drivers.



* Imports for wood pellet production (export to EU); came to a halt in 2011

** Expected to increase further

**Figure 11**: Wood chip trade flows for energy in Europe in 2011 (Lamers et al. 2011).

## 4.3 Impacts of Support Measures

Since markets tend to emphasize short-term gains over long-term profit, ensuring the long-term economic sustainability of bioenergy production requires the assistance of non-market mechanisms (FAO 2010). Transaction costs are typically large when a new market develops and decrease as the market begins to mature (Lunnan et al. 2008). To overcome market weaknesses of the developing bioenergy sector, policy-makers in the climate and energy sector apply multiple policy instruments simultaneously (Kautto et al. 2011). Support policies can be described as either demand or supply side policies. In the bioenergy sector, regulatory policies and fiscal incentives such as feed-in tariffs and subsidies are used to influence fuel choice, subsidize production costs and to support technology investments (Table 3). Direct subsidies are used on the supply side to stimulate biomass harvesting and enhance its profitability. Some policies are also designed to change consumption and consumer behavior.

Another public policy tool is to support research and development (R&D), but this does not affect the market directly.

**Table 3.** Policies for renewable energy production (REN21 2012)

| | **Regulatory policies** | | | | | | **Fiscal incentives** | | | | **Public financing** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed-in tariffs | Electric utility quota obligation/RPS | Net metering | Biofuel obligation/ mandate | Heat obligation/ mandate | Renewable energy certificates (REC) | Capital subsidy, grant, or rebate | Investment or production tax credits | Reduction in sales, energy, $CO_2$, other taxes | Energy production payment | Public investment, loans, or grants | Public competitive bidding |
| **Argentina** | • | | | • | | | • | • | • | • | • | • |
| **Australia** | * | | | * | | • | • | | | | • | |
| **Austria** | • | | | • | | • | • | • | | | • | |
| **Belgium** | | * | • | • | | • | • | • | • | | | |
| **Brazil** | | | | • | | | | | • | | • | • |
| **Canada** | * | * | • | • | | | • | • | • | | • | • |
| **China** | • | • | | • | • | | • | | | • | • | • |
| **Czech Republic** | • | | | • | | • | • | • | • | | • | • |
| **Denmark** | • | | • | • | | • | • | • | • | | • | • |
| **Estonia** | • | | | • | | | • | | • | • | | |
| **Finland** | • | | | • | | • | • | | • | • | | |
| **France** | • | | | • | | • | • | • | • | | • | • |
| **Greece** | • | | | • | | | • | • | • | | • | |
| **Germany** | • | | | • | • | | • | • | • | | • | |
| **Hungary** | • | | | • | | | • | | • | | • | |
| **Ireland** | • | | | | * | • | | | | | | • |
| **Italy** | • | • | • | • | • | • | • | • | • | | • | • |
| **Japan** | • | • | • | | | • | • | | | | • | |
| **Latvia** | • | | | • | | | | | • | | • | • |
| **Lithuania** | • | | | | | | | | | | • | |
| **Mexico** | | | • | | • | | | • | | | • | • |
| **Netherlands** | | | | • | | • | • | • | • | • | | |
| **New Zealand** | | | | | | | • | | | | | |
| **Norway** | | | | • | | • | • | | • | | • | |
| **Poland** | | • | | • | | • | • | | • | | • | • |
| **Portugal** | • | • | • | • | • | | • | • | • | | • | • |
| **Russia** | | | | | | • | • | | | | | |
| **Spain** | • | | | • | • | | * | • | • | | • | |
| **South Africa** | | | | | | | • | | | | | • |
| **Switzerland** | • | | | | | | • | | • | | | |
| **Sweden** | | • | | • | | • | • | • | • | • | | |
| **United Kingdom** | • | • | | • | | • | | | • | • | • | |
| **United** | * | * | * | • | * | • | • | • | • | • | • | • |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **States** | | | | | | | | | | | | |

*= policies are implemented on state- or province level, but not nationally

More than half of the countries involved with IEA (see http://www.iea.org/countries/) have included information and education measures in their energy policies to stimulate the development of a skilled workforce (Roos 2002). Although highly mechanized and developed harvesting methods require fewer employees than less mechanized methods, the lack of an adequate workforce can be a barrier to economically sustainable biomass wood supply. The shortage of skilled harvester drivers remains a problem especially in Nordic countries, where the cut-to-length harvesting method requires more education and experience to be productive. These information and education policies aim at inducing more young people into forest education and increase the number of skilled workers.

### 4.3.1 Direct Subsidies for Feedstock Production

Direct subsidies lower the costs of harvesting and create a so-called *push-effect* that increases the supply of woody biomass (McKenzie & Sershun 2010). Subsidies related to the production and harvesting of woody biomass are rare in the EU (Anon 2008). In Finland and Sweden, bioenergy has received longstanding government policy support and direct subsidies for biomass procurement (Lunnan et al. 2008).

Subsidies are offered for thinning and chipping of small-sized energy wood as a form of the so-called Kemera-subsidy in Finland. Subsidies enable feedstock chains based on whole tree chips to be competitive (Figure 12 a&b). State subsidies for feedstock harvesting are 7 €/m$^3$ and 4.25 €/m$^3$ for chipping (Ericsson et al. 2004, Laitila et al. 2010). There are strict limits for the eligibility of young stands and all together less than 10% of forest chips produced receive subsidies annually. In France, tax incentives are also available to carry out forestry work to allow for greater timber and biomass extraction (Anon 2008).

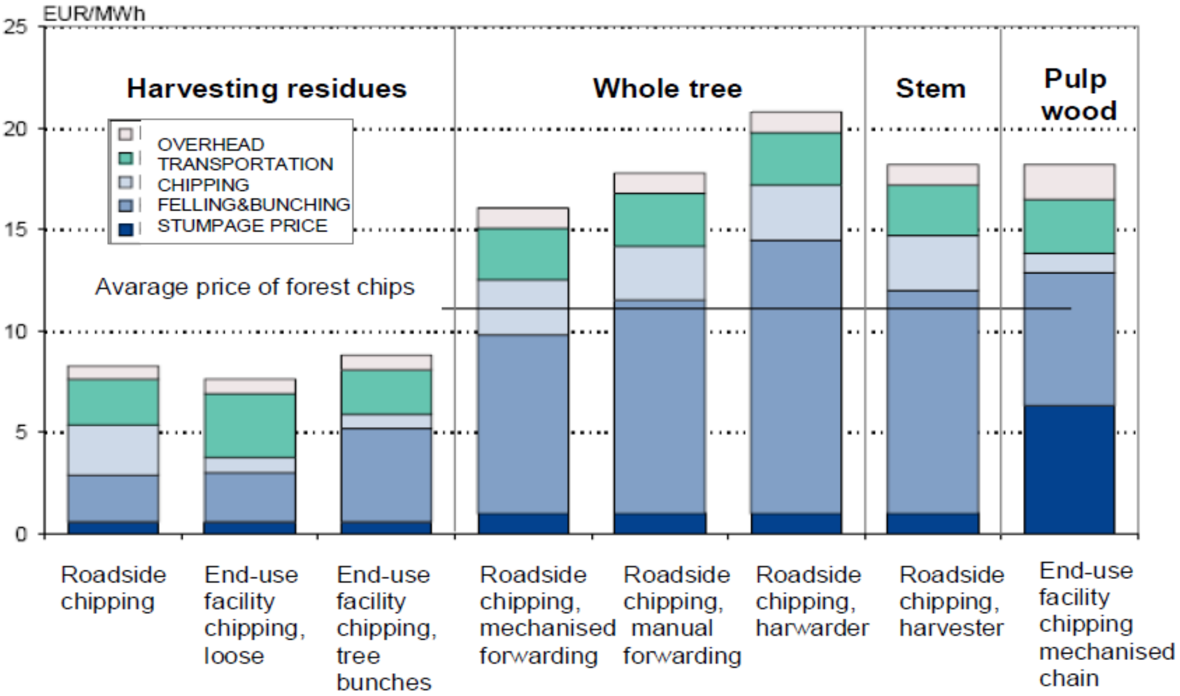


**Figure 12a.** The cost structure of forest chip supply chains without subsidies in Finland (Pöyry 2006).

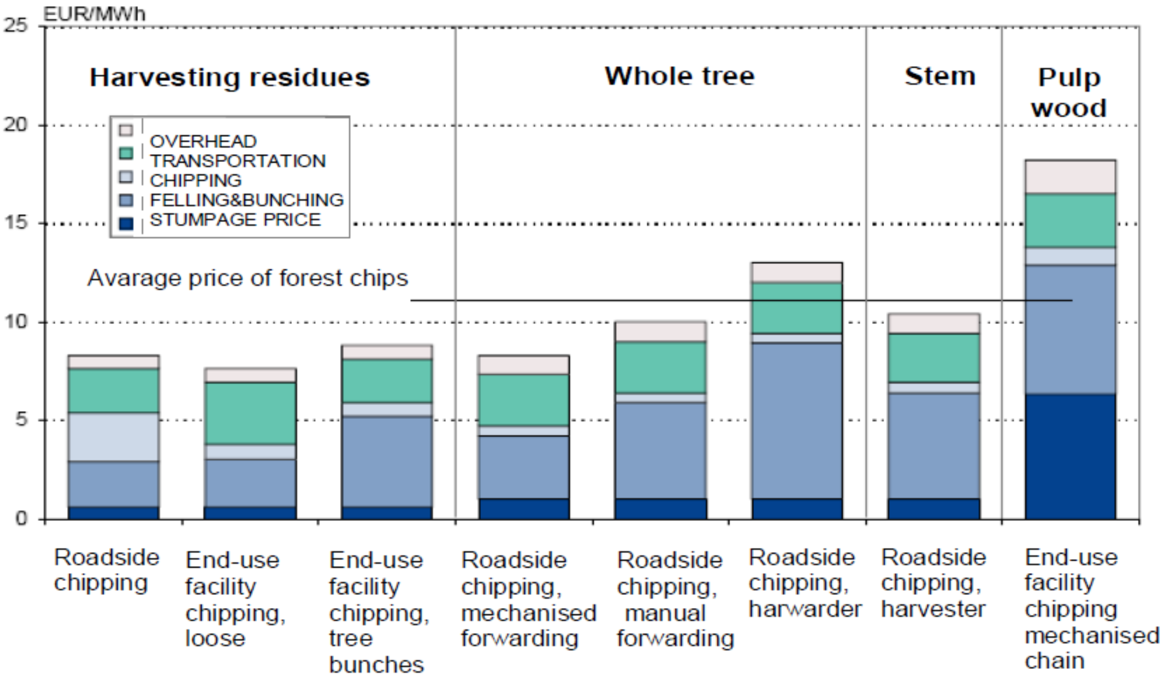


**Figure 12b.** Subsidies improve the profitability in whole tree feedstock supply chains (Pöyry 2006).

In the USA, Federal and State governments have helped create markets for renewable energy through tax incentives and mandates, but harvesting of small-sized energy wood is not currently subsidized. Most of the incentives and grants offered are for liquid biofuel production, wind energy and solar projects (USDA 2006). Previously, grants for utilization of forest biomass derived from preventive treatment sites were offered, of up to $20/tonne, but this mechanism has since been discontinued (Hubbard et al. 2007).

### 4.3.2 Indirect Subsidies of Green Electricity Generation

New or developing business sectors typically experience a situation where costs constitute a barrier for market entry and small producers may have difficulties accessing markets. Small bioenergy producers or low-capacity operators in particular experience difficulties achieving economic sustainability because they do not have the necessary economies of scale (FAO 2010). Supportive policies encouraging bioenergy production, including biomass-based electricity production are currently offered in many countries. Energy policy is also influenced by government ambitions to reduce energy prices by restructuring and deregulation of electricity markets (Roos 2002).

Indirect subsidies and incentives can raise the profitability of biomass-based electricity production compared to competitive energy sources, by decoupling forest chips prices from $CO_2$ price fluctuations and reducing feedstock cost fluctuations facing energy producers. Subsidies can create a *pull-effect* or *demand-pull* into the market, and can increase the biomass feedstock supply volumes (McKenzie & Sershun 2010). Subsidies for electricity production can include feed-in tariffs or fixed prices and tax grants for biomass-based electricity production.

In Central Europe, fixed prices for green electricity were successful at initiating growth in the renewable energy sector for some technologies (particularly wind), but were much less successful for biomass. Overall, wood-based electricity production seems to benefit the most when fixed electricity prices are set at a sufficiently high level and established alongside additional measures to address other barriers such as planning issues or fuel supply. Canada offers capital and investment subsidies and feed-in tariffs at the provincial level for power from renewable resources. In USA, Federal renewable electricity production tax credits (PTC) are targeted toward electricity production. In 2012, the tax credit was 2.2¢/kWh for wind, geothermal, and closed-loop biomass and 1.1¢/kWh for other eligible technologies. In general, it applies to the first 10 years of operation (U.S Department of Energy 2012). To qualify for PTC, energy generation firms must sell the energy on the market at current market prices (Hubbard et al. 2007).

In Finland, new subsidies focused on wood-based electricity production are tied to $CO_2$ prices. Larger subsidies of 18€/MWh are paid when $CO_2$ prices are 10 €/t$CO_2$ or less and 0 €/MWh when $CO_2$ price is 23 €/t$CO_2$ or more (Figure 13). These subsidies are effective in raising the quantity of forest biomass used in heat and power production (Kallio et al. 2011).

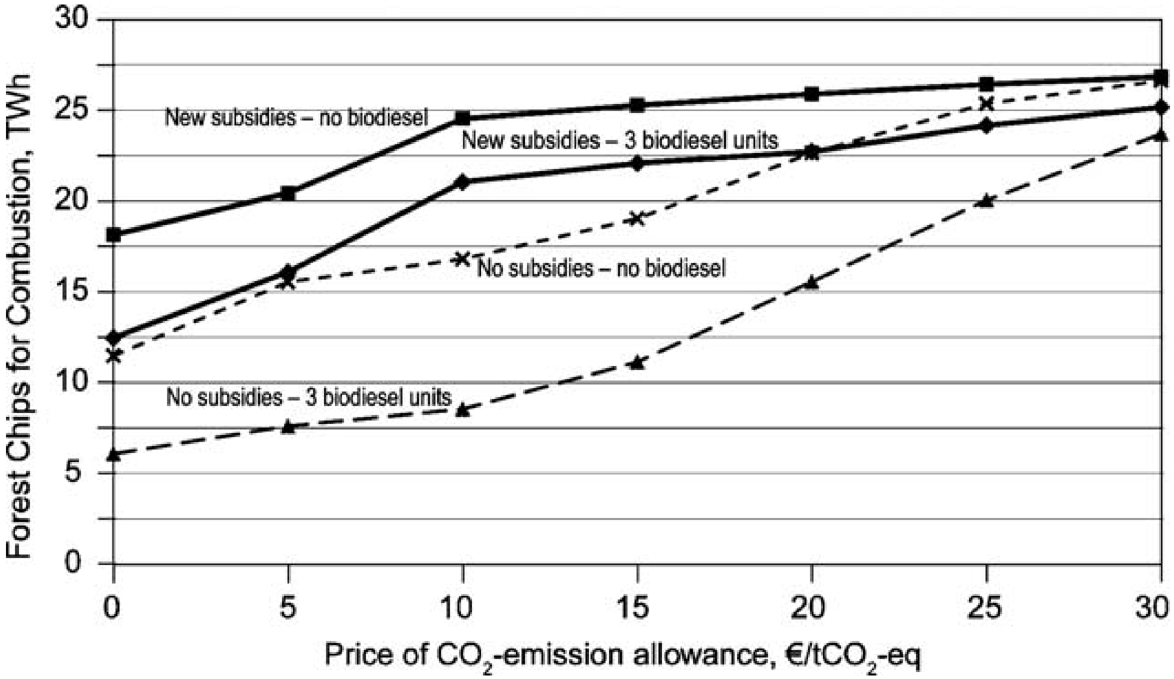


**Figure 13.** Supply/use of forest chips in heat and power production under alternative CO2 prices, given the level of roundwood harvests in 2007 (Kallio et al. 2011).

By 2020, some 25 TWh of forest chips are projected to be used for energy production in Finland, but this target can only be met if $CO_2$ prices are above 25€/t$CO_2$. Production of biodiesel tightens the competition over chips and diminishes the amount available for energy production when the $CO_2$ prices rise (Figure 13). Subsidies focused on wood-based electricity production help to increase the competitiveness of chips for combustion and more biomass is directed to energy production (Kallio et al. 2011).

To promote renewable energy production and use effectively, subsidy mechanisms must be carefully designed. Subsidies and tax grants distort the cost-competitiveness of different energy sources and affect the availability of forest resources for other competing uses (FAO 2010).

### 4.3.3 Technology Development

Bioenergy markets are growing steadily, but new technologies and investments often need support to become commercially viable. Financial incentives, subsidies, taxes or tax grants are available in most of the IEA member countries to assist new technologies or investments in bioenergy production (Table 3). Investment subsidies for energy facilities can offset up to 40% of the eligible costs if investment is directed toward new technology (Thornley & Cooper 2008). Investment subsidies for existing technology (e.g. renovation, moderation) can offset up to 30% of those costs (Alakangas et al. 2011). Investment subsidies that encourage increasing energy wood consumption are known as discretionary incentives. These subsidies are allocated mostly for small or medium-sized energy facilities and they can be applied from local state authorities for new renewable energy projects or to improve energy security.

Investment subsidies granted to renewable energy projects in Europe have helped to stimulate the sector, but have not resulted in sustained positive impacts. Subsidies tend to change frequently due to changing policies. Differences within a country and levels of subsidies between countries can also form barriers (Fagernäs et al. 2006).

The share of biomass and biofuel investments of total renewable energy investments has declined during the past few years (Figures 14, 15). The downward trend has been driven by uncertainty over changing subsidies and energy prices. This discourages new long-term investments as they are often considered too risky (Thornley & Cooper 2008). From 2007 to 2011, the majority of new investments in the renewable energy sector have been based on wind or solar power and less on biomass and biofuels (Figure 14, 15).

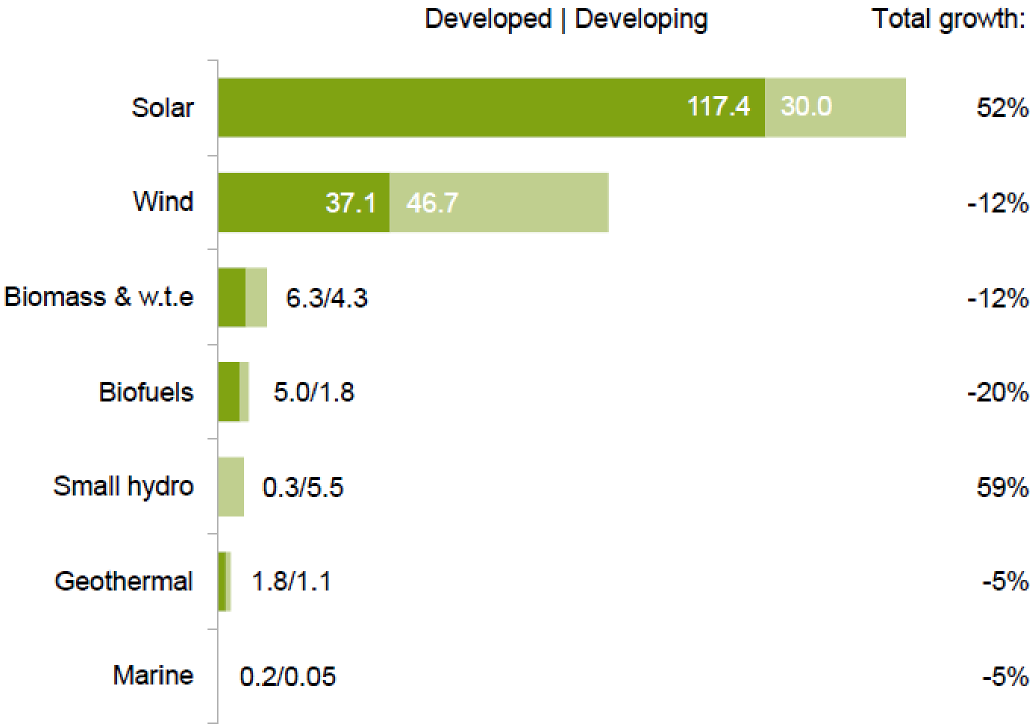


**Figure 14.** Investments made in renewable energy technologies in developed and developing countries in 2011 and total growth rate in 2010, $bn (Bloomberg New Energy Finance 2012)

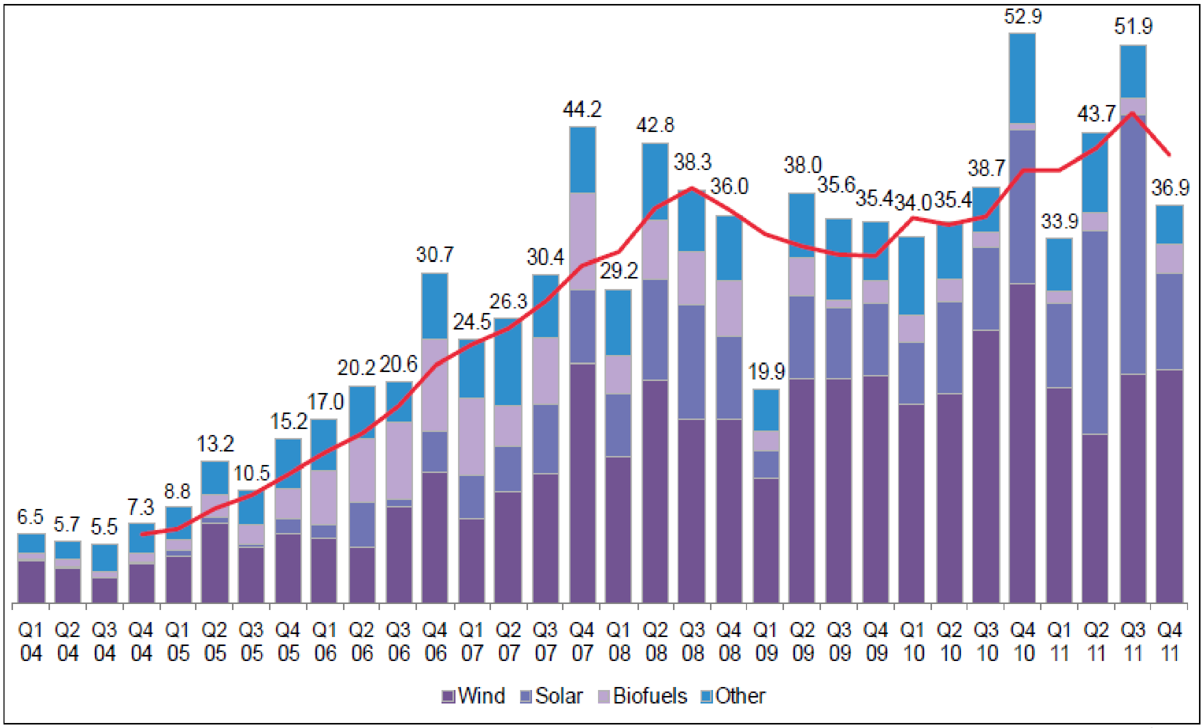


**Figure 15.** Global financial new investments in renewable energy, quarterly trends 2004-2011, $bn. Since 2010, investments in biomass and biofuels have declined 12% as investments in other renewables have increased (Bloomberg New Energy Finance 2011).

In countries where the forest bioenergy sector is well established, the impact of investment subsidies on sector development has been smaller than in countries in which the share of forest bioenergy of total primary energy production is smaller (Thornley & Cooper 2008). At the moment China is the lead investor in renewable energy and India displayes the fastest expansion rate in the world with a 62% increase in renewable investements in 2011 (Bloomberg New Energy Finance 2012).

In 2011, developed economies finally began to strengthen their share of investment in renewable power and fuels after several slower years (Figure 16). However, the recent performance of developed economies owes a great deal to a jump in USA asset finance and a boom in small-scale investments in Italy and Germany (Bloomberg New Energy Finance 2012). In the US alone, total investments raced ahead by 57% in 2011.

In countries with fewer forest resources, other barriers have remained in spite of positive effects from investment subsidies. In the United Kingdom, subsidies have increased biomass-based electricity production, but barriers such as planning restrictions and fuel supply issues hold back additional development (Thornley & Cooper 2008). The transition to economically feasible, larger-scale production will demand new logistical solutions, long-term contracts and supply partners. Unstable markets make it difficult to sign long-term, high-volume contracts (Faber et al. 2005).

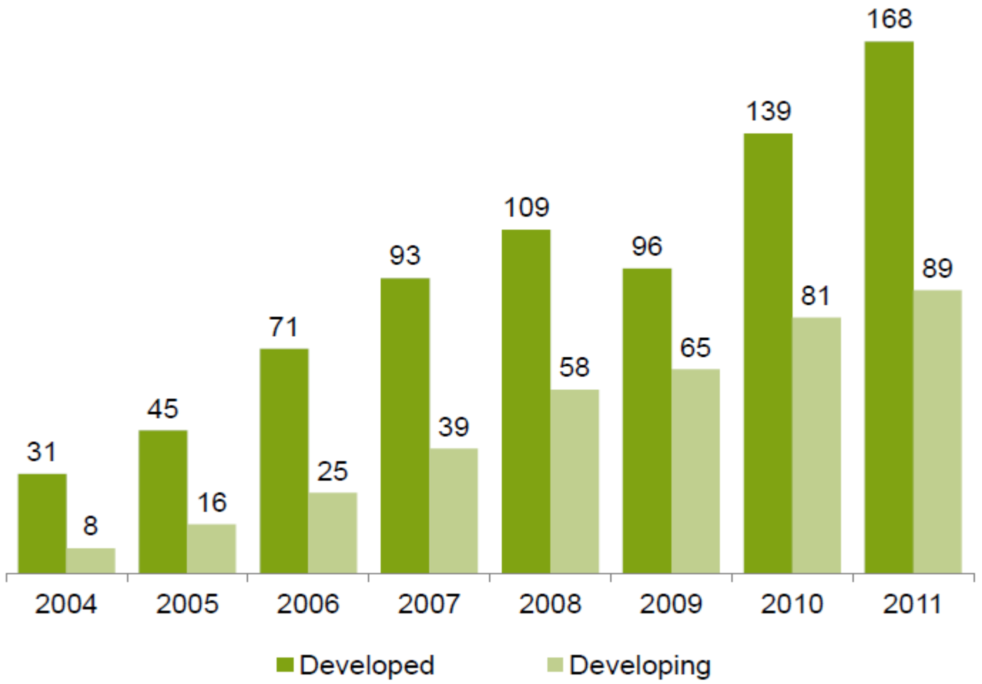


**Figure 16.** Global new investment in renewable energy in developed and developing countries, 2004-2011, $bn (Bloomberg New Energy Finance 2012).

Energy industries are pushing for a stable, long-term subsidy, specifically targeted at forest bioenergy. In many instances, a combination of policies such as green certificates, feed-in tariffs together with investment subsidies have proven to be the most successful approach (REN21 2011).

### 4.3.4 Risks Related to Subsidies

Policies function as key drivers as well as potential barriers for bioenergy development. Subsidies are needed in order for energy wood harvesting, transportation and bioenergy production to be competitive. For example, in Finland, energy wood procurement is not economically profitable at the current energy prices without state subsidies (Heikkilä et al. 2009). The reliance on state subsidies is not economically sustainable over the long term.

The lack of coherent and long-term national renewable energy policies can be seen as a significant barrier to renewable energy development. Inadequate and poorly coordinated policies slow growth in bioenergy use and could reduce the willingness of forest owners to sell energy wood in the market. Another potential barrier is that policies regarding different, but related sectors are often conflicting; a holistic approach is needed to stimulate an increased utilization of bioenergy and new investments (Fagernäs et al. 2006). Often several groups within government are responsible for bioenergy policy, such as ministries of energy and environment, economy and trade, agriculture and education. This suggests that, while necessary, achieving an integrated, harmonized policy for bioenergy development may be institutionally difficult (Florin & Bunting 2009).

More generally, uncertainty related to changing emission reduction targets and the sharing of emission allowances increases the investment risk in some economies. The unequal playing field between countries that have agreed to reduce emission levels and countries that have not, affects investment conditions and companies' willingness to use biomass.

## 4.4 Investment in Machinery

A complete bioenergy supply chain includes machines and vehicles for harvesting, transportation and processing operations. Machine costs can be divided into fixed, capital costs and variable, production costs. Fixed costs are harder to influence because they stay constant when output varies. Expensive machines incur high capital cost and must be utilized close to their full capacity to be economic, and therefore investments in machinery pose a high risk to private entrepreneurs (Asikainen et al. 2002). There are also factors which firms do not have any control over, such as interest rates and tax rates. High interest rates increase the cost of capital and entrepreneurial risk. Thus, annual productivity, capital costs and other operational factors considerably affect the economic sustainability of biomass procurement.

Commercial operators have some control over their capital structure and should strive to achieve optimal use of machinery and capital. The cost of investment choices made by individual companies can be calculated by the relative opportunity cost of forgoing the next best alternative. When an asset such as capital is used for one purpose, the opportunity cost is the value of the next best purpose the asset could have been used for. Opportunity cost can be included in risk assessment analysis, but is not treated as an actual cost in annual financial statements.

Cost structures of the machines differ considerably between regions due to differences in labor, fuel and investment costs. European and Scandinavian countries utilize forest biomass on a larger scale than the United States.  Harvesting technology and organizational structure used in the feedstock chains are also different (Table 4).

**Table 4.** Machine investment costs (Jylhä et al. 2010, McNeel et al. 2008, and Pulkki 2012)

| **Investment cost on the machinery** | | | | | |
|---|---|---|---|---|---|
| **North America** | **Feller buncher** | **Grapple skidder** | **Stroke delimber** | **Slash bundler** | **Biomass truck** |
| **Purchased price US$** | 260 000 – 400 000 | 225 000 | 350 000 | 250 000 | 130 000 |
| **Salvage value (% of price)** | 25 | 25 | 25 | 25 | 25 |
| **Economic life (years)** | 5 | 5 | 5 | 5 | 5 |
| **Europe** | **Harvester** | **Forwarder** | **Biomass truck** | **Timber truck and trailer** | |
| **Purchased price €** | 350 000 | 225 000 | 278 000 | 223 000 | |
| **Salvage value (%** | 40 | 40 | 40 | 40 | |

| | | | | | |
|---|---|---|---|---|---|
| **of price)** | | | | | |
| **Economic life (years)** | 4.6 | 4.6 | 4.6 | 4.6 | |

In Europe, mechanized harvesting using harvester-forwarder chain or harwarder (single machine for harvesting and forwarding) is the dominant method of forest bioenergy harvesting. Harvesting can also be carried out by manual logging, in which forwarders are used for roadside transportation (Laitila 2012). Currently, most of the bioenergy produced is currently from logging residues, small trees and otherwise unmerchantable wood. Logging residues are collected when merchantable wood is harvested. Small-sized energy-wood and otherwise unmerchantable wood is harvested from thinning, treatment sites or as an integrated harvesting together with industrial wood using whole tree method or cut-to-length method. Stumps are collected from final felling sites, mainly in the Scandinavian region (Andersson et al. 2002).

The purchase cost of a modern-day harvester-forwarder is between 450 000 € to 600 000 € (Table 4). Ranta et al. (2007) found that using a harvester-forwarder supply chain, the capital costs constitute around 17-23% of delivering costs of woody biomass in Finland.

Minimizing the capital costs tied up in harvesting machinery is important since the seasonal variations in biomass harvesting are high. Seasonal variations affect the profitability especially in small and medium-sized harvesting companies. To lower investment cost and minimize risks, the same base machinery should be used for harvesting of forest energy as is used in harvesting of industrial round wood, requiring only relatively low-cost attachments, such as changeable felling heads. The extraction of residual biomass from the forest can be done with a standard forwarder that is also used for round wood (Asikainen et al. 2011).

In North America, the whole-tree method, sometimes called full-tree method, is the main method of biomass harvesting. In this system, feller-bunchers fell and bunch timber, which is then transported to landing or roadside for delimbing and stocking (Pulkki 2012). A typical harvesting system used in full-tree harvesting would include a feller buncher, grapple skidder, stroke delimber and slasher. In the United States and the west coast of Canada, the majority of woody biomass harvesting is from logging residue. Another potential source of forest biomass comes from thinnings (BRDB 2008).

The average investment cost for highly mechanized feedstock chains capable of handling the harvest and recovery of woody biomass ranges from $800 000 to $1 200 000 depending on the region and harvesting conditions (Table 4). Procurement and capital costs are the main expenses in the woody biomass harvesting and machine costs can constitute about 31 to 50% of delivered wood costs in the United States (McNeel et al. 2008, Hubbard et al. 2007). Gross operational costs to cut and move biomass to the roadside can range from $30 to over $117 per dry ton, depending on type of operation, terrain, and number of trees to be treated (USDA Forest Service 2005, Skog et al. 2006). The costs associated with cutting and skidding constitute about 45-50% of total costs (Leinonen 2004).

Thinning treatments using conventional forest harvesting equipment can become unprofitable when the size of trees removed is less than 8” (20.3 cm) diameter at breast height (Kluender et al. 1998). This makes small-diameter thinnings less cost-effective and highlights the need for development of better systems (BRDB 2008). Equipment designed for harvesting small material (mulching machines, purpose-built small-diameter harvesters) and other technologies need additional evaluation on costs, performance, and compatibility with fuel reduction objectives. Further advances in harvesting, hauling, and processing machinery would create cost savings and make the feedstock supply chain more viable in the future (BRDB 2008).

## 4.5 Storage Management – Controlling Quality and Capital

One of the most difficult tasks in biomass procurement is managing the storage of the biomass feedstock prior to the end use (Nurmi 1999). Forest biomass can be stored either at the roadside, in terminals, or on the plant site in storage units. By storing the biomass, companies can use stored biomass to even out seasonal employment, balance raw material supply, and reduce idle time.

Woody biomass quality can be defined as the suitability of a certain type of wood for a specific purpose. From the economic sustainability point of view, the goal is to maximize the added value of the products and the production process (Andersson et al. 2002). The role of storage and the drying process in the feedstock supply chain is critical for producing quality biomass and maximizing the heating value of biomass. Proper storage in uncomminuted form can maintain the quality of the fuel (Jirjis 1995). When the goal is to produce quality biomass for energy production, heating value is critical. The smaller the energy plant, the more important the heating value of the fuel becomes. The heating value of the fuel is determined by the moisture content; moisture content and particle size distribution are the most important physical parameters that determine fuel quality (Figure 17).

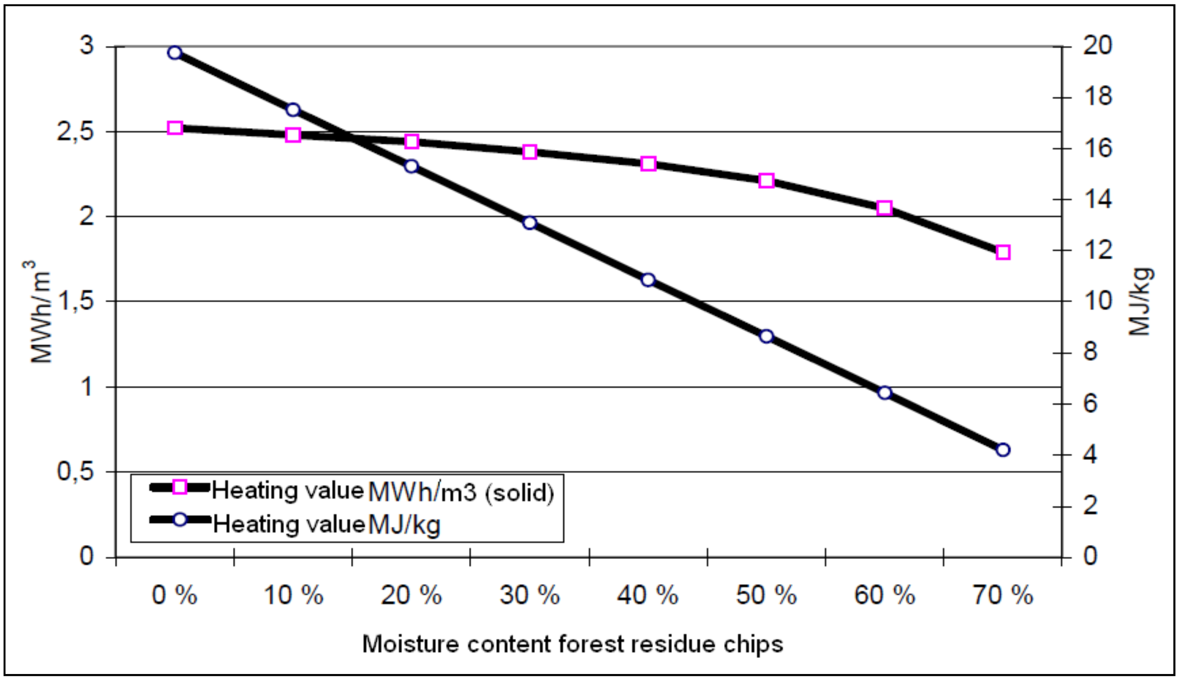


**Figure 17.** The effect of moisture content on heating value of chips (Alakangas 2000).

Moisture may be lost by drying the forest biomass in the field or in storage. A moisture content of as low as 30% can be reached under favorable conditions. In a case study done by Brunberg et al. (1998), the heating value of wood material increased by 12% during storage. The heating value could be further increased, but storage may also cause considerable losses of raw material (Stupak et al. 2008, Asikainen et al. 2002). Wood moisture content affects the cost of transport as well because the transported product is energy (Figure 18). The more water that is in the material, the lower the volume of fuel wood per load of a given weight (Andersson et al. 2002).

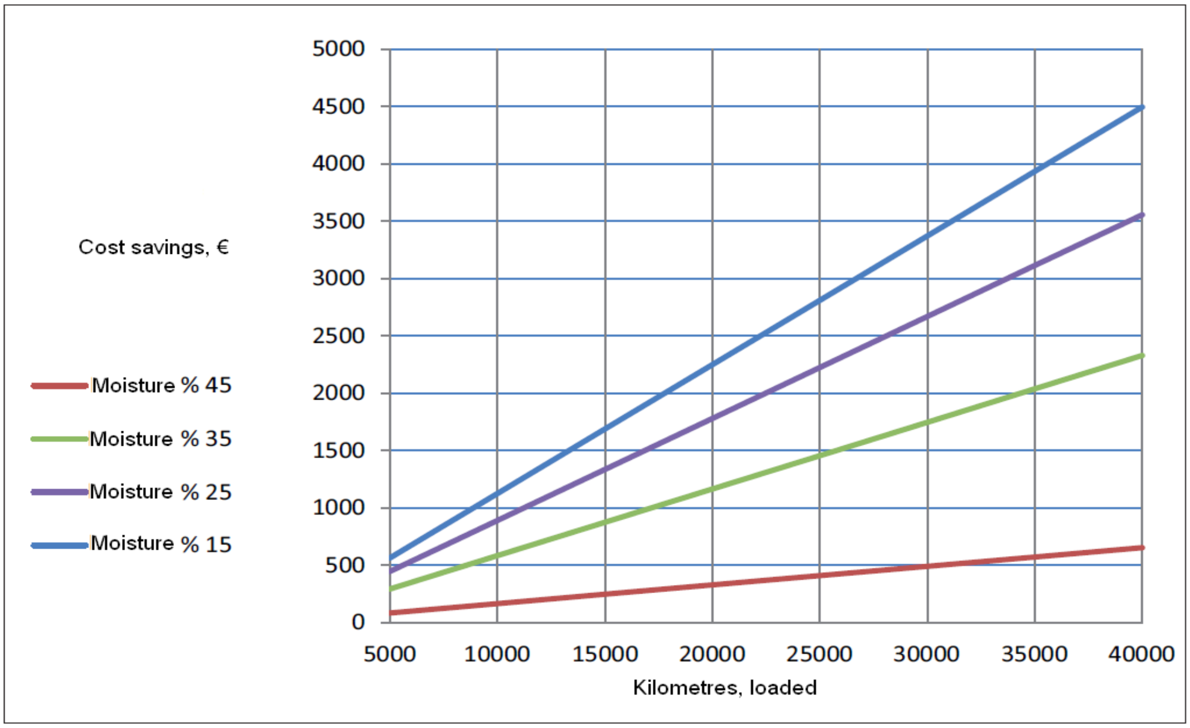


**Figure 18.** Cost savings in transportation in different moisture contents in Scandinavian procurement conditions. The carrying capacity of the truck is 37 000 kg and load size 48 m$^3$ (Hakonen & Laurila 2011).

Achieving higher quality feedstock usually increases costs throughout the whole supply chain. For example, chips made from delimbed trees have the lowest moisture content and more even particle distribution, but harvesting costs of delimbed trees are higher than whole-trees (Stupak et al. 2008). Using terminal systems increases feedstock quality by controlling the moisture content and impurity levels, although these are not very cost-competitive. The most important disadvantages to terminal storage systems are high capital costs, high maintenance costs and very high storage costs.

Storing also has adverse effects that may reduce the quality of the wood fuel, especially in large buffer storage units due to the uneven moisture distribution and uneven drying within the storage pile, which reduces the quality of fuel chips. Over time, the interior of the pile warms up and moisture condenses in the cooler outer and upper parts of the pile. Abiotic processes such as moisture adsorption, hydrolysis, pyrolysis, chemical oxidation and charring cause further dry-matter loss and generate heat. During storage, the ash content of logging residue chips can increase up to 50% in one year as a result of decomposition processes (Andersson et al. 2002).

Long term storage weakens the profitability of the feedstock supply chain because large amounts of capital are tied up in storage for several months and degradation and dry-matter losses of biomass may also occur. Dry weight reduction during storage of biomass has been observed in many trials.  Fresh logging residue chips stored in a large pile for seven months lose approximately 12% dry matter, mainly during the first few weeks (Thörnqvist and Jirjis 1990).

## 4.6 Seasonal Variation of Demand and Fleet Utilization

Profitability and economic sustainability of biomass energy production are further increased by a constant supply of wood (Valsta & Häggblom 2009). Biomass feedstocks are produced relatively evenly throughout the year, but differences in the supply and demand do occur, especially in district heat production (Jirjis 1995). In larger plants, the demand for woody biomass may fluctuate according to the particular fuel mix that is used. Biomass feedstock supply should be based on customer demand, which means that it is in greater demand during the winter (Nurmi 1999). High seasonal variations may weaken the profitability of small and medium-sized harvesting companies and cause seasonal unemployment.

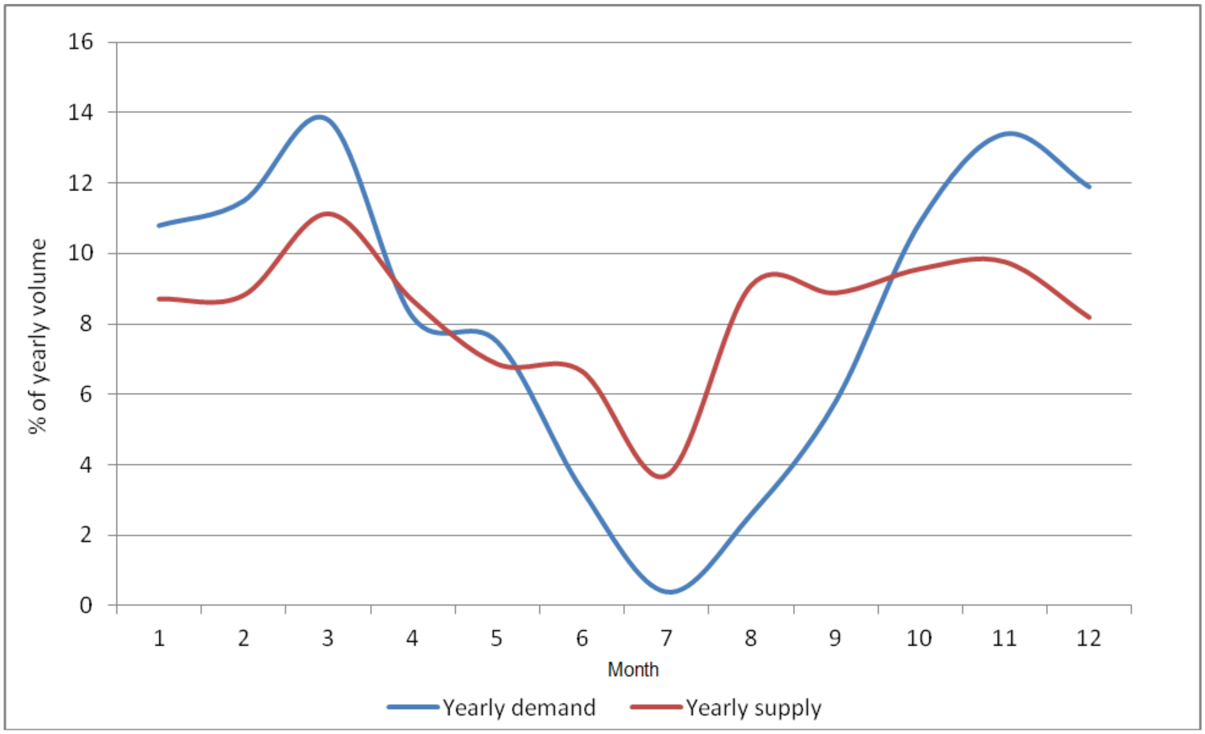


**Figure 19.** Seasonal differences in supply and demand can be large in the Scandinavian region (adapted from Hakkila et al. 2001).

In boreal regions and areas where the demand is primarily for heat, the demand curve strongly correlates with seasonal temperature changes and winter demand can be seven times larger than demand in the summer (Figure 19). In the municipal sector, the supply network of biomass can be geographically very patchy, making it more difficult to secure raw material supplies (Ranta et al. 2005). In temperate zones, biomass is also used for district cooling but demand variations are smaller than in boreal regions. In North America, the seasonal variations are much smaller than in Europe and the harvesting and pre-processing of the biomass are typically completed within several days (Hubbard et al. 2007, Andersson et al. 2002).

Seasonal variations in demand and supply can be addressed by storing the excess biomass in buffer storage facilities at plant sites, terminals or at the roadside. There are three principal ways of solving the seasonal balance problem (Andersson et al. 2002):

- Storing feedstock during periods of low demand -- sufficient storage capacity within a storage network guarantees that supply can meet demand during peak load seasons.
- Alternative uses of storing production capacity during periods of low demand -- capital costs can be minimized by temporary recruitment of contractors.
- Utilizing equipment from other operations during periods of high demand, seasonal use of basic machinery that is used elsewhere, e.g. agriculture -- this combines low capital costs in machinery and storage with flexible operational management.

Buffer storage systems are used in areas where winter conditions will prevent contractors from supplying consistently when demand is at its peak (Nurmi 1999). The sizes of buffer storage units vary, but normally a two to three week reserve is stored at the plant site. The use of buffer storage will increase feedstock supply costs because it creates more handling and storage, but it also acts to increase the availability and security of forest biomass supply (Ranta et al. 2012). By optimizing harvesting methods, storage points and storing time in the supply chain, the whole feedstock supply chain can become competitive and flexible.

# 5.0 IMPROVING THE EFFICIENCY OF BIOMASS FEEDSTOCK SUPPLY

## 5.1 Operational Efficiency and Environment

According to Pfeiffer (1967), operational efficiency can be defined as "the effectiveness with which human potential and capital are utilized in a production system". Similarly, Sundberg & Silversides (1988) state that operational efficiency addresses "the problem to allocate in space and time, labor and machines, to put them to work in a rational fashion and to maintain or improve their efficiency". The assumption by Sundberg & Silversides (1988) is that operational efficiency can be increased by addressing three crucial issues that are of a *technical*, *social* and *economic* nature.

The *technical* issues relate to the different materials, tools, and machines that are necessary in order to harvest, process, and transport the biomass from the forest to the end-use facility. It may also include processes related to selecting, preserving, and enhancing the techniques used to execute the job (Sundberg & Silversides 1988). At a technical level, each link in the supply chain can be analyzed and improved separately in order to benefit the entire supply chain.

*Social* issues that should be addressed relate to work safety, health issues, human capital, and work satisfaction. The aim for *economic* issues is to "balance the inputs of man, machines and other assets for performing the job so as to meet the objectives" (Sundberg & Silversides

1988). The underlying objective is to carry out the work at the lowest possible cost. In the context of this report, it means to produce energy from forest biomass that is economically sustainable in the short and long term.

The term efficiency is vague and often associated with economic efficiency. However, in regards to the overall operational efficiency simply looking at economic efficiency is not sufficient. Ahn & Dyckhoff (1997) defined efficiency as “do[ing] the right things right” in their characterization of efficiency and effectiveness, which is considered a good definition for forest-based biomass supply chains as well. In this context, the ‘right things’ are factors that improve operational efficiency to make supply chains better and more efficient than the status quo. Foundational work to determine the ‘right things’ has been done by Pfeiffer (1967). Pfeiffer (1967) states that operational efficiency can be increased in several ways: by adapting the methods of operation, using different materials and equipment, educating the labor force, improving the work place through better environmental conditions and working climate, standardization of working methods, and the integration of operations. Finally, a holistic viewpoint is important to maintain since it considers the whole system as compared to just looking at a single operation in one environment. In the context of forest biomass for energy, Röser (2012) concluded that the concept of efficiency by Ahn & Dyckhoff (1997) should be expanded to account for the complex interrelationships of forest biomass supply. Röser (2012) suggests adding another dimension to the original definition, that is an efficiency: time ratio. The definition for operational efficiency in forest biomass supply for energy should therefore state “do[ing] the right things right, at the right time”. By doing the right things at the right time, operational efficiency can be improved with small steps that do not necessitate large capital investments or fundamental changes to the existing supply systems.

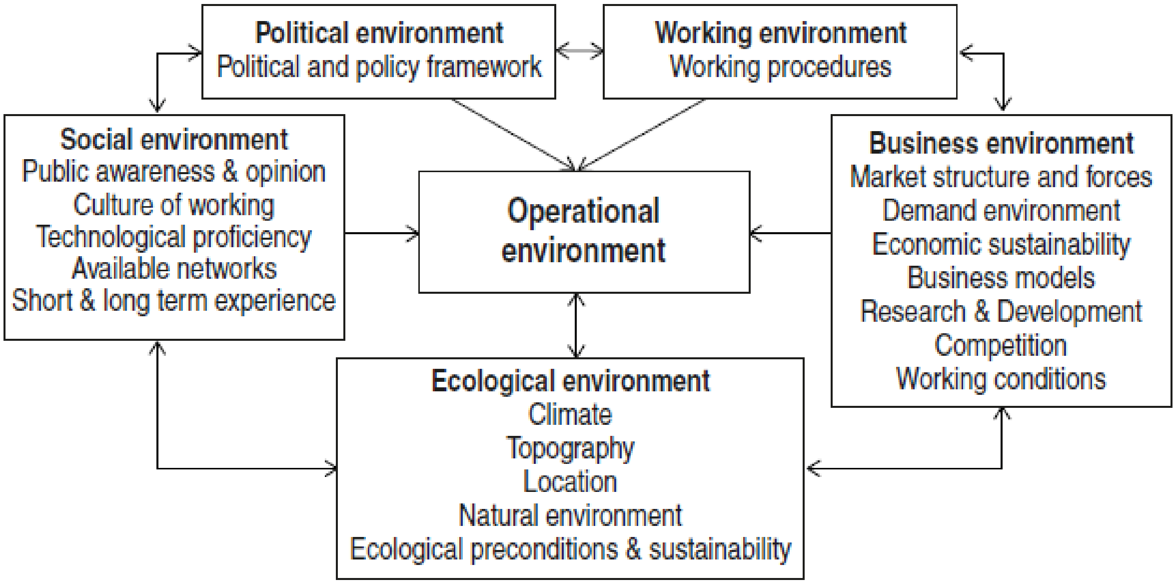


**Figure 20.** The concept of the operational environment in the forest biomass for energy supply chain (Röser 2012).

The operational environment is an important aspect of operational efficiency as it affects all stakeholders in the biomass supply chain. The operational environment describes the environment in which people or a system work, but also includes the internal and external factors that affect everyday operations. These factors include the political and policy framework, the working culture in a certain region, the cultural background, exposure to knowledge and technology and climatic conditions. The concept of operational environment related to the supply of forest biomass for energy, as introduced by Röser (2012) is presented in Figure 20.

Figure 20 illustrates the large number of factors affecting the operational environment of biomass supply chains. As the operational environment differs for each individual supply chain, each supply chain has to be planned and adapted carefully to ensure economic sustainability. The operational environment also includes the optimal location of the bioenergy plant, and consequently has a large effect on the operational efficiency of the entire supply chain. In some cases, the operational environment might also prevent a bioenergy operation to become established due to limiting factors within, for example the political or social environment.

The study by Röser in 2012 underlines the importance of a thorough planning process and the need for optimal timing of operations for each of the different dimensions discussed above: technical, social and economic (Figure 21). Such details are needed to establish economically viable supply chains. Some of the technical considerations necessary to ensure operational efficiency have been discussed in section 4.

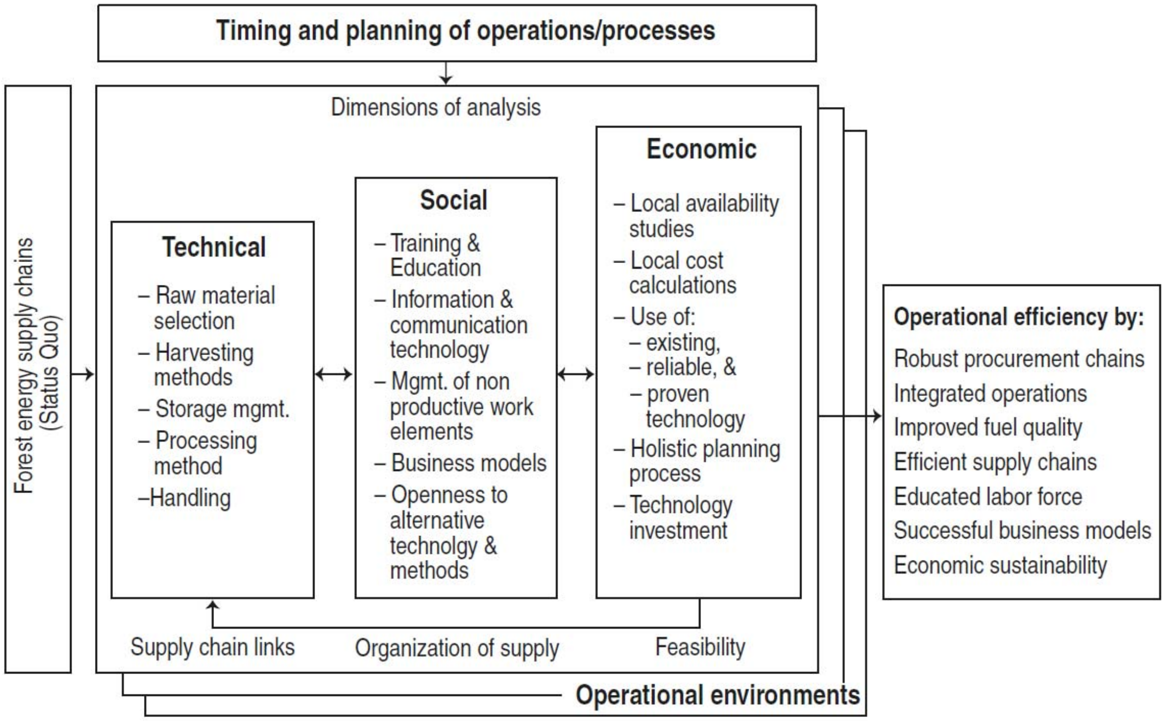


**Figure 21.** Three-dimensional approach to examining and establishing forest energy

supply chains (Röser 2012).

The considerations are as follows:

Technical considerations of operational efficiency:

- Selection of suitable raw material according to customer demands
- Optimal timing of the harvesting operations, and pile setup to promote debarking and drying
- Selection of an optimal debarking method during harvesting
- Selection of a proper storage system for a given feedstock and condition
- Optimizing the process and effective equipment maintenance
- Careful handling of the raw material before chipping
- Use of existing, reliable, and proven technology

Social considerations of operational efficiency:

- Training and education of all actors in the supply chain
- Implementation and uptake of new information and technology advances into existing and new supply chains
- Design of holistic modern flexible supply chains, based on proven technology
- Establishment of business models that promote trust among the different actors in the supply chain
- Identification and subsequent elimination of unnecessary activities in the supply chain
- Consideration of all aspects of the operational environment and its effects

Economic considerations of operational efficiency:

- Local feedstock availability and cost studies prior to establishment of plant
- Use of existing, reliable, and proven technology
- Holistic planning to address all aspects of the operational environment and its effects
- Investment in optimal technology to produce the desired fuel quality

On a regional level, Röser (2012) demonstrates that by changing some of the traditional organizational structures, new innovative ways of operation and organization of the work can be achieved. By changing or adapting these structures, it is possible to develop new business models to improve the efficiency of the supply systems both for roundwood and forest biomass for energy. New business models enable the direct elimination of unnecessary and duplicate processes. This is particularly interesting for regions and countries with long histories of forestry such as Germany, Austria and the UK.

Increasing operational efficiency should focus not only on raw material selection, but also on increasing efficiency by modifying the elements in the supply chain when necessary, e.g.

chipping. This means finding the proper technologies and optimizing the maintenance schedule.

The results by Röser (2012) demonstrate that cost effectiveness can be achieved with very minor modifications to existing supply chains, for example, by optimal timing of operations and by relying on proven technology. Increasing the operational efficiency of the forest biomass supply will help to establish a new supply chain and improving the existing supply chains.

## 5.2 Optimal Location of Bioenergy Business

Procurement costs remain the major impediment for large-scale biomass when competing with fossil fuels (Gan & Smith 2006). In wood-based energy production it is difficult to achieve the same economies of scale as fossil fuels because of the disadvantages of transporting widely distributed biomass to a central location (Figure 22). This weakens the economic sustainability of wood-based energy production (Ranta 2005).

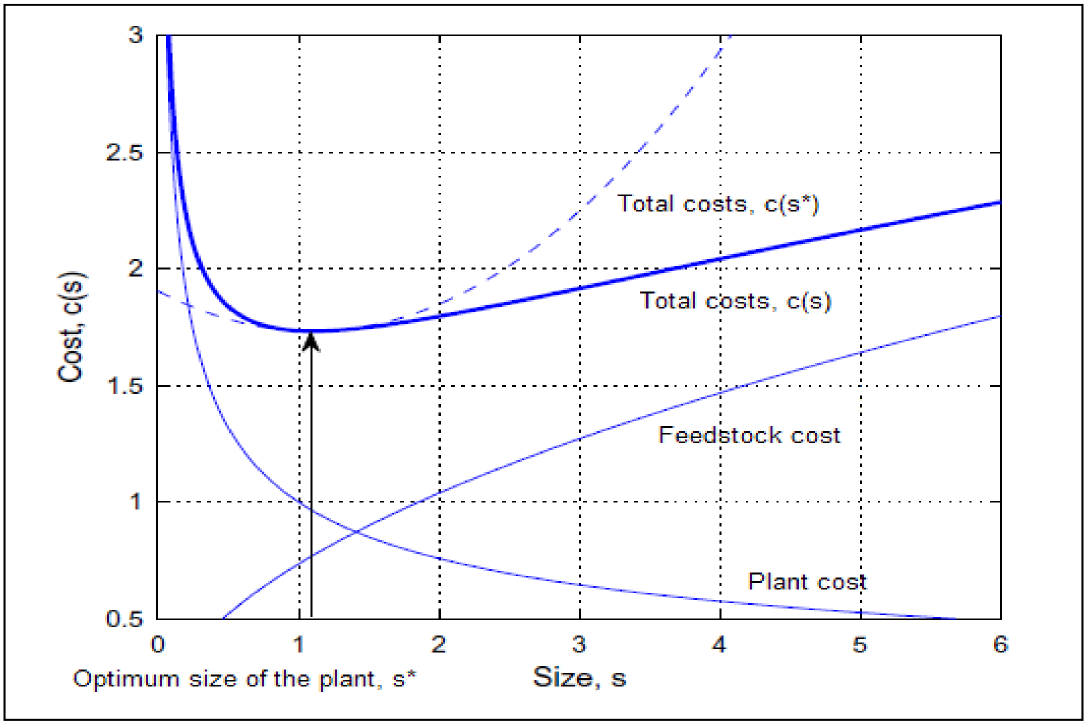


**Figure 22.** The existence of an optimum scale is illustrated by plotting c(s) = C(s). Plots of feedstock cost and plant costs are also shown. The dotted line c(s*) is showing the curvature of c(s) close to the optimum s* (Jack 2009).

The greater the output of an energy-producing plant, the higher the yearly consumption and the higher the procurement costs of biomass will be, resulting in higher total operating costs (TOC) per unit of energy produced (Figure 23). When the annual consumption of forest chips in a single plant increases from 10 000 $m^3$ to 100 000 $m^3$, the mean procurement costs increases by 8-15% (Asikainen et al. 2001).

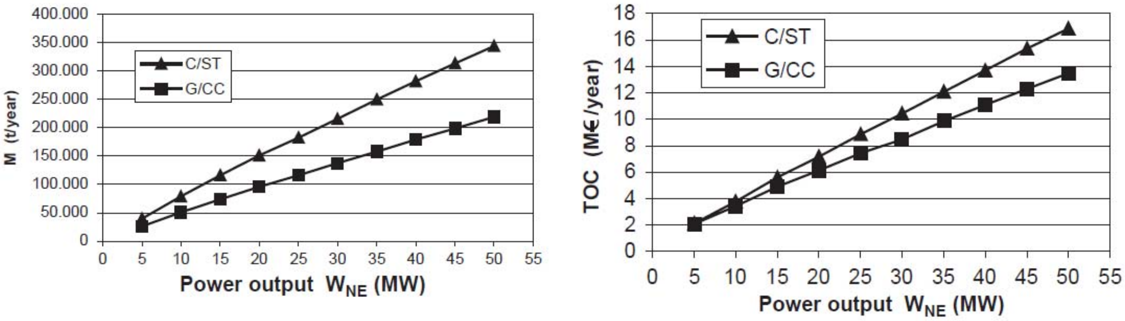


**Figure 23.** Estimated yearly biomass flow rate M (t/year) and total operating costs (M€, TOC) for different plant sizes and production processes. $W_{NE}$= net electric energy power output (MW), C/ST= fluid bed combustor and steam turbine cycle, G/CC = fluid bed gasifier and combined gas- steam cycle (Caputo et al. 2005).

The price of woody biomass is highly variable due to the low energy-intensity and transport economy. Improvements in the productivity of biomass production, harvesting, and transport systems are clearly the key to enhancing the bioenergy share of total energy production (Gan & Smith 2006). The overall cost reduction potential is estimated to be up to 25%, mainly due to better technology, improved harvesting techniques and optimized long-distance transportation (Hogan et al. 2010).

When estimating the optimal plant size, the trade-off between capital costs and capacity must be considered. Larger plants are usually more fuel efficient, but consume more biomass, which increases the radius of biomass procurement and total operating costs. Correspondingly, the capital costs in relation to production capacity are reduced (Figure 23). The radius of the procurement district around the plant is defined by the annual use of forest fuels at the plant and the annual harvestable amount of forest fuels in the area surrounding the plant. When availability and procurement costs are summarized, the cumulative availability, total costs and marginal cost of biomass procurement can be calculated (Karjalainen et al. 2004).

The costs and availability of woody biomass vary largely between countries. From an economical point of view, optimal stands for biomass harvesting should have a high density ($m^3ha^{-1}$) of harvestable biomass, forwarding distance should be less than 500 meters and long distance transportation should be less than 100 kilometers (Stupak et al. 2008). More remote areas may not be as economically suitable for harvesting due to higher transportation costs, but if demand increases these resources may have to be utilized. As biomass is transported further, more transportation fuel is used. Additional fuel consumption reduces the life cycle energy efficiency of the whole production chain and increases the life cycle carbon dioxide emissions, both undesirable outcomes from a sustainability point of view (Reichling & Kulacki 2011). One possible solution is to replace large biomass plants with several smaller facilities closer to feedstock resources, but this may also result in higher capital costs and reduced operational efficiency.

In principle, the cost of competing fuel defines the maximum acceptable cost of forest biomass. When the marginal cost of forest biomass use exceeds the mean cost of alternative fuels, using biomass for energy is not economically sustainable. Optimization of the feedstock supply chain has therefore a significant environmental and economical value. Decreased procurement costs will increase the optimum scale of operations and make new volumes of resources available (Andersson et al. 2002). By integrating the biomass supply chain within the roundwood supply chain or by using cooperative structures in biomass feedstock supply, management and long-distance transportation cost savings can be achieved and overall profitability in the supply chain increases. Networking is a means of seeking new opportunities for enhancing such aspects as flexibility, quality, and the reliability of deliveries (Kuitunen et al. 1999).

## 5.3 Risk Management

Financial uncertainty can be comprised of endogenous and exogenous dimensions. Endogenous uncertainty arises from the nature of the internal (i.e. project and organization level) environment. Exogenous sources of uncertainty arise at three levels: industry, competition and external environment. Industry level uncertainties originate primarily from financial risks related to technological innovations and changes in the relative prices of inputs and outputs (Franck 2008). Competitive risk represents the actions of competitors that cannot always be predicted. Uncertainty in the external environment refers to the risk present in the operating environment and markets. Environmental uncertainties arise from political surroundings, macroeconomics, social climate, and financial volatility (Franck 2008). For companies involved in bioenergy production and supply, the unstable political environment and volatile financial conditions create uncertainties.

Risk management involves identifying, analyzing and reducing the risks and possible financial losses. Such losses and liabilities can affect day-to-day operations, reduce profits, and cause financial hardship severe enough to cripple or bankrupt a small business (Franck 2008). Basic risks such as fires, accidents, product liabilities, and employment practices are a profound part of risk management in many companies, but these events usually do not drive companies into financial difficulties.

Therefore, more attention has been paid to financial risk management—such as interest rates, foreign exchange rates, and risks associated with changing technology, competing fuel prices and unique threats concerning that particular sector (Franck 2008). For companies operating in biomass feedstock use and supply, large investments represent the most significant risk.

A biomass supplier can manage the risks by either moderating the investment costs or increasing the efficiency of harvest and delivery. In conditions where seasonal variation is high, using the same base machinery for the harvesting of different forest products from industrial roundwood to energy wood reduces the financial risks, smoothes the demand peaks of one sector and ensures full operation of the machinery year around. Lowering the investment costs also reduces the barrier to entry for new operators.

# 6.0 SOCIAL VALUES

As previously discussed, economic sustainability has a social dimension linked to it and socio-economic impact studies are commonly used when evaluating the sustainability of biomass feedstock supply or bioenergy development projects. Typically, these are measured in terms of economic indices, such as employment, accessibility and affordability. Local socio-economic impacts are diverse and will differ according to such factors as the nature of the technology, local economic structures, social profiles and production processes.

One principal in sustainable supply chain management is the selection of responsible suppliers. The first step is to evaluate all possible suppliers in terms of their social impacts (Hutchins & Sutherland 2008). There is significant potential for forest products and forest bioenergy projects to contribute to positive social values associated with sustainable development, especially in poor, rural, or forest dependent communities. A company seeking to achieve sustainable operations should consider the entire supply chain for its products, not just those links that belong to its own sphere of legal responsibility.

The production and use of bioenergy can benefit communities and stakeholders involved in direct and indirect ways. Direct benefits are both economic and social because of the net employment that is often generated (Richardson 2002). Bioenergy systems may influence the number and quality of jobs at a local level, and have profound influence on the quality of life in homes and communities and have an effect on affordability and accessibility of energy (Gan et al. 2012).

In particular, creation of new and long-term employment in rural areas improves social welfare in the region. The use of woodfuels and other biomass resources in energy production can generate 20 times more local employment per energy unit than other energy alternatives. Direct employment comprises jobs involved in woodfuel production, transport, construction, operation and maintenance of plants (FAO 2010). The number of jobs and net earnings is influenced by the production method and organization. Manual methods and mechanized systems generally require different levels of employment and earnings (Borsboom et al. 2002). In countries with high goals for renewable energy, but relatively low availability of domestic biomass resources, biomass imports are increasing, and in these situations, it must be expected that possible net employment benefits are achieved at international scales.

Accessibility and affordability of wood fuels to local residents are also key measures when evaluating the social sustainability of biomass production. Bioenergy is considered more socially sustainable than fossil fuel alternatives because the money spent on energy remains in the local community. In contrast, over 90% of money spent on heating oil is typically lost from the local economy (Borsboom et al. 2002). Bioenergy can lower the cost of heating, but the lack of access to woodlands can limit the viability of woodfuel systems, as for example in remote areas with few woody resources or in areas near conservation reserves.

Indirect social values are often estimated through multipliers, which are quantified by the ripple effects of bioenergy investments and use such as jobs and wealth generated within the economy (FAO 2010). Other indirect social benefits can result from local, participatory involvement in decision-making regarding the location of and system design for new bioenergy schemes. When different stakeholders and local people have the opportunity to participate in and influence local decision-making processes concerning bioenergy, increases in several important aspects of social sustainability can occur (FAO 2010).

Apart from employment and rural development, there are a number of other social concerns in woody biomass, woodfuel, and bioenergy production (FAO 2010, Buytaert et al. 2011). These include, for example risks to health and worker safety, human and labour rights, food safety and security. Occurrence of work-related illnesses, accidents or aesthetic impacts for local people may occur; for example, potential health risks from airborne fungal spores and hyphal fragments may occur because of handling wood chips (Andersson et al. 2002). Companies must determine how to properly consider human and labour rights when biomass is produced in or exported from countries with weak protection of these rights.

Social and economic impacts of bioenergy systems are complex and highly variable. Social values are often indistinguishable from economic ones due to the nature of the interrelationships. The complexity increases as economic and social values are integrated with environmental values.

# 7.0 ENVIRONMENTAL VALUES

The incorporation of bioenergy in the overall fuel mix, and associated processes of growing and utilizing forest biomass, generally contributes to the development of energy systems that are more environmentally friendly than competing fossil fuels. In many cases, the substitution of biofuels (used broadly here to include all solid, liquid and gaseous sources of bioenergy) for fossil fuels leads to reduced net greenhouse gas emissions in the short term and even more so in the long term (Bird et al. 2011; McKechnie et al. 2011). When reductions of greenhouse gas emissions are estimated using Life Cycle Assessment (LCA) techniques, emissions along the whole supply chain need to be considered.

While development of profitable forest biomass harvesting and production systems in most cases will have positive synergies with the creation of greenhouse gas savings, there can be a trade-off between profitability and measures needed to protect other environmental values. As noted by Hakkila (2002), this is the result of several operational changes including planning and training intensity, machine design, harvest site and landscape layout, number of interventions, and harvest utilization standards for separating tops, branches and foliage. Such environmental risks associated with bioenergy production systems are addressed in a range of criteria and indicators, such as those proposed for biodiversity, soil and water values (Lattimore et al. 2009, FAO 2010). These impacts are usually associated with the first link in the supply chain, i.e. biomass production and associated land management.

The environmental effects of forest management were thoroughly reviewed by authors contributing to Richardson et al. (2002). This effort included an assessment of environmental risks and development of guidance and mitigating practices to ensure environmental sustainability for soil, water, and biodiversity in forests managed for bioenergy feedstocks. Guidance for reducing the environmental impact of bioenergy production systems proposed by Hakkila (2002) suggested practical alternatives, which forest managers can apply to maintain environmental quality while also achieving financial profitability. For example, an assessment of the risks associated with utilization of nutrient-rich foliage typically suggests that this biomass be left on site. This can be accomplished by drying logging residues on the harvest site for one season. Such practices require a sequence of individual harvesting operations, which will be more expensive compared to a single, integrated harvesting method (Hakkila 2002). However, the amount of logging residues that should be left onsite to protect soil fertility may correspond to the amount of biomass that is left on the site operationally due to machine handling and felled-tree breakage. Nurmi (2007) reported that it was not operationally feasible to remove the last 30% of the aboveground biomass from mechanically logged sites in Finland. Experience with commercial boilers indicates that nutrient-rich biomass, high in ash content, causes slag accumulation on boiler tubing. This is a good example of consistency between environmental management objectives and feedstock priorities for bioenergy conversion technologies. Another example from recent research conducted by Gan and Smith (2010) demonstrated that on soils in the southeastern US, where loblolly pine growth is often limited by phosphorus availability, retaining phosphorus-rich crown biomass could reduce the need for applying expensive fertilizer, thus achieving environmental and financial objectives simultaneously.

Woody bioenergy feedstocks can be collected from a wide range of forestry production systems ranging from extensive gathering of small amounts of fuelwood to highly intensive energy cropping systems with frequent interventions and total utilization of roots and tops, as discussed in detail by Burger (2002) and Mead and Smith (2012). As a result, the associated risk of significant environmental change in response to bioenergy feedstock production varies. The change may be positive, for example, where soil quality is improved and landscape diversity is increased by management practices and design. The environmental response to bioenergy feedstock harvesting may also be negative; for example Helmisaari et al. (2011) recorded growth depressions after bioenergy feedstock harvesting.

Practices to maintain and enhance soil and site productivity are typically site specific due to differences in climate, soil and water conditions, and atmospheric deposition (Raulund-Rasmussen et al. 2008, Stupak et al. 2008). Protective measures may result in limitations to biomass harvesting and production that will lead to lower profitability of the operation, for example if multiple operations are needed to replace integrated operations (Hakkila, 2002). However, protection of environmental values may also help to ensure long-term productivity and profitability, cf. the abovementioned studies by Gan and Smith (2010) and Helmisaari et al. (2011).

There is continual tension between the empirical knowledge and uncertainty about the consequences of our actions. Sometimes Adaptive Management has been adopted (e.g. see the FSC Boreal Standard (FSC 2004)) to provide a logical framework for incorporating validated best practices into current management while seeking continual improvement. Adaptive Management involves a commitment to monitoring and reviewing the effects of our actions and comparing with goals set in initial planning stages. This process has been referred to as the “plan-do-check-review” cycle for seeking continual improvement in a management system. The Adaptive Management framework as described by for example, Mayfield et al. (2007) also provides an opportunity for all stakeholders to have input in defining the management objectives, in reviewing monitoring results, and in developing a response for future action that might seek continual improvement in the overall management system. The Adaptive Framework also makes provision for the management system to take into account all regulations that apply (e.g. at the local and state level) so that operations will be in compliance with any laws. Therefore, if the intent of Adaptive Management is adopted by managers and conducted in an open and transparent fashion, any management system can, in principle, be based upon the best knowledge available, continually improve over time as new knowledge becomes available through research, and be in compliance with all legal regulations that apply.

# 8.0 GOVERNANCE

The movement of biomass and bioenergy products along the supply and value chain takes place in response to a variety of economic signals between actors who sell or buy goods and services. The markets that develop around such activity are affected by a variety of voluntary and strictly enforced laws and regulations designed to accomplish various political, economic, social and environmental goals. As noted in the criteria and indicators of the Montreal Process (Montreal Process Working Group 2005), provision of an adequate legal, policy and institutional framework is essential to achieve sustainable forest management. These laws, policies and institutions vary around the world, and a complex array of such arrangements is common in many countries.

In the bioenergy sector, various government policies provide incentives to stimulate bioenergy production to achieve a variety of renewable energy policy goals. Other government policies that apply at local, regional and even international levels are designed to protect, maintain and enhance environmental quality and protect human health. Therefore, it is common to perceive a tension line of “checks and balances” between governance mechanisms designed to stimulate renewable energy development and those governance mechanisms that in effect restrain development as a consequence of attempting to achieve other goals.

The proponents of various “checks and balances” are often from different schools of thought when it comes to prioritization of economic, social and environmental values, and the political decision making process that affects the direction of development is influenced by the relative “power” of the proponents of one value system versus another over time. Bioenergy supply chains are very strongly affected by the cumulative effects of the multiple layers of governance that come into play, for example, as biomass moves along the supply chain from privately owned forest land in the south-eastern US, which includes a mix of uncertified and certified forest, to a wood pellet producer and exporter on the Atlantic coast of Georgia and finally to a pellet-coal co-fired power plant in Belgium (Figure 24).

The objective of this section of the report is to briefly discuss the types of governance mechanisms that come into play along the bioenergy supply chain from producers of feedstocks to energy consumers. The term "governance" is used here to refer to a variety of best management practice guidelines, voluntary schemes and systems, and strictly enforced regulations that in one form or another set standards for satisfying sustainability principles and criteria that apply to land management activities and the energy products that consumers purchase.

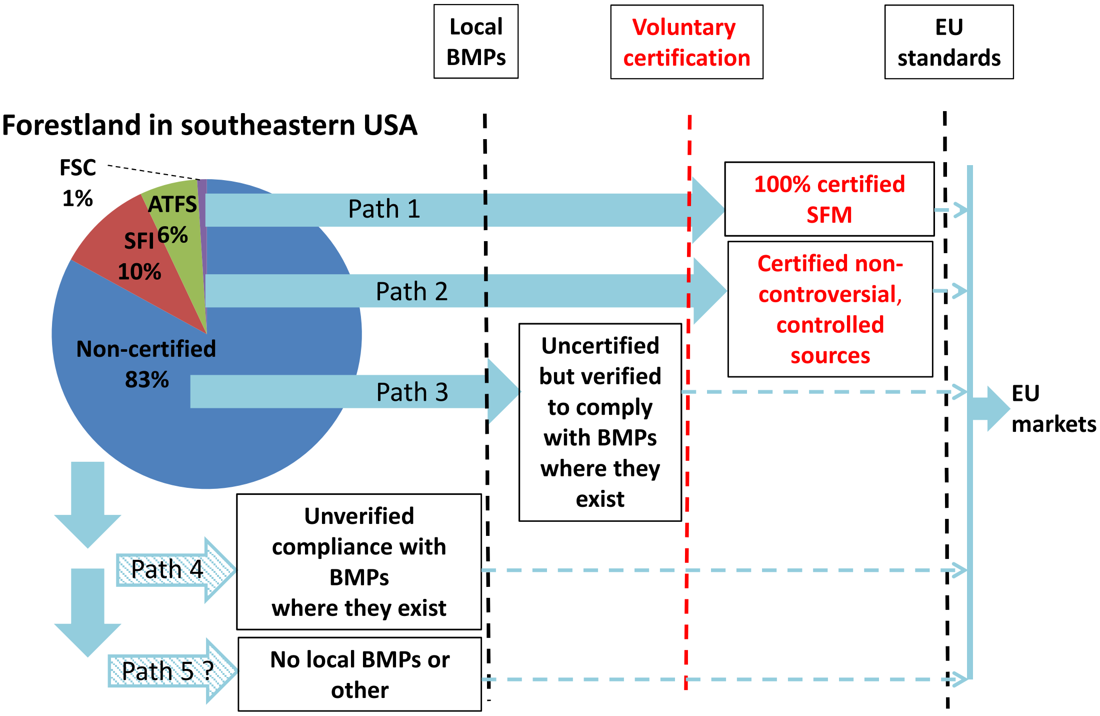


**Figure 24**. Multiple claims for exports from forestland in the southeastern USA to EU markets. At this point, it is uncertain if the governance mechanisms and certification schemes that ensure the sustainability of the US forest sector will satisfy anticipated new EU-RED standards for solid bioenergy feedstocks (adapted from Kittler et al. 2012).

Forestry supply chains can involve a number of horizontally and vertically integrated actors (Table 5). Some of these actors contribute to the flow of biomass and bioenergy products along the supply chain, and others are involved in various governance roles. Examples of governance roles, as we currently understand the sector, include the development and operation of voluntary sustainability certification schemes, the activities associated with standards setting, certification and auditing according to these standards.

Other examples are the various roles that government officials play in developing and enforcing local to state and national and international standards of performance and regulations affecting operations, trade and the flow of goods and services. The business itself may also decide on commitment to the Triple Bottom Line (TBL, social responsibility, environmental soundness, and economic viability), and thus have its own systems to ensure protection of social and environmental values in relation to its activities. This also includes investors that may have systems to ensure responsible social and environmental planning of new projects, including for example a screening to determine if an Environmental Impact Assessment (EIA) is necessary (e.g. World Bank 2010). Attempts have been made to develop the EIA methodology for bioenergy projects (Fritsche et al. 2010).

**Table 5.** The types of roles filled by people actively involved in any aspect of the bioenergy supply chain, including activities designed to ensure sustainability of the bioenergy supply chain.

| **Role in bioenergy supply chain** | **Description** |
|---|---|
| Landowner or manager; biomass producer | Forest owner or manager, farmer, agricultural cooperative, owners and managers of energy crop farms, palm oil plantations and similar actors. |
| Contractor | Entrepreneur contracted to perform activities such as planting, harvesting, pesticide application, transportation, etc. For example forestry or agricultural entrepreneurs, and transportation and storage. |
| Biomass refiner | Producer of secondary solid or liquid biofuel products, for example woodchips, pellets, vegetable oils, ethanol, biodiesel, etc. |
| Trader or distributor | Organization or person that buys and sells biomass or biomass products on a market. Such actors may also blending liquid biofuels. |
| Energy producer | Producer of electricity and/or heat from biofuels. |
| Investor | Investor in bioenergy or bioenergy related projects, e.g. International Financial Institutions. |
| Certification scheme or initiatives | Existing or newly developing organizations or initiatives setting standards for achieving a sustainable production of biomass, biofuels or bioenergy. |
| Certifying body | An independent, third party organization that evaluates stakeholders seeking first time certification, issues certificates and ensure on-going conformance with a certification scheme. |
| Auditor | On-the-ground auditor of certification standards aimed at achieving sustainable bioenergy. May be an employee of a certifying body or an independent consultant hired by a certifying body. |
| Standards development support | Association or partnership dealing with social and environmental standards. They are working with established and emerging voluntary standard systems and develop guidance and help strengthen the effectiveness and impact of these standards. They may work with companies, non-profits and governments to support their referencing and use of voluntary standards, and may also define codes of good practice for setting social and environmental Standards (e.g. ISEAL alliance, GBEP, GIZ, ISO). |
| Administrator (public authority) | Institution that enforces laws and regulations (set by the legislator) and in different ways regulate actors involved in the biomass, biofuel, and bioenergy sector and administrates legislation and regulations related to sustainable bioenergy systems. For example county administrative board, municipality, etc. |
| Regulator (public authority) | Jurisdictional institution at the regional, state, provincial, national, or international level (e.g. the European Union, countries, Bundesländer in Germany, states in the USA, etc.), which set laws and regulations in relation to aims of achieving sustainability of biomass production or the whole bioenergy supply chain. |
| Expert | Expert not listed above that provides advice on any aspect of sustainable bioenergy production systems, for example researcher, agricultural and forestry consultant. |
| Bioenergy association | Non-governmental organization actively involved in developing bioenergy systems, with different types of members, including economic operators on the market, but also e.g. consultants, researchers, and other individuals. |
| Professional organization, society or association | Non-governmental professional organization with members being economic operators on the bioenergy markets (e.g. forest owner, wood pellet or biofuel producer associations). |
| NGO | Non-governmental environmental organization actively involved in questions around bioenergy sustainability. |

A wide variety of governance mechanisms come into play, for example along the wood pellet supply chain mentioned above, from south-eastern US forests to Belgian co-fired electricity production. Each of the actors along the supply chain may face multiple levels of governance mechanisms (Table 6), which range from voluntary to strictly enforced regulations.

**Table 6.** Governance mechanisms that affect or may potentially affect the bioenergy supply chain for wood pellets moving from southeastern US forests to Belgian co-fired electricity production. See also Fig. 24.

| **Bioenergy supply chain actor** | **State-enforced regulations and BMPs for environmentally friendly land management, including soil, water and biodiversity** | **Triple Bottom Line: standards and systems for a responsible business (e.g. Corporate Social Responsibility and procedures for Environmental Impact Assessments)** | **Voluntary certification for sustainable land management, procurement, chain of custody (CoC), or sustainability along the whole supply chain** | **International sustainability standards affecting import-export trade (e.g. requirements similar to the EU Renewable Energy Directive[a]; EU Timber Regulation)** |
|---|---|---|---|---|
| Biomass producer, forestry | Yes; incl. voluntary guidelines and BMPs for forest management and harvesting | Yes | Yes; incl. self-selected schemes such as American Tree Farm System, Sustainable Forestry Initiative, Forest Stewardship Council, or a scheme to show compliance with legislation of import countries[a]. | Depends on the vertical integration of the producer and standards, for example if proof of sustainable feedstock sourcing is required and a CoC is required. |
| Contractor | Yes; incl. state forester monitored application of BMPs | Yes | Yes, incl. self-selected schemes such as Master Logger, Smart Logging. | Depends on the vertical integration of the contracting company and standards. |
| Biomass refiner | No[b] | Yes | Yes; CoC certification standards, or a scheme to show compliance with legislation of import countries[a]. | Depends if the biomass fuel is traded to markets with international sustainability requirements. |
| Trader or distributor | No | Yes | Yes; CoC certification standards, or schemes to show compliance with legislation of import countries[a]. | Depends if the biomass fuel is traded to markets with international sustainability requirements. |

| | | | | |
|---|---|---|---|---|
| Energy producer | No[b] | Yes | Yes; Energy certification standards, or schemes to show compliance with legislation[a]. | Depends if international standards affect the supply chain and production of the energy producer |

[a] The EU is currently discussing whether to decide on legislative sustainability criteria for solid and gaseous biomass fuels used in electricity, heating and cooling, with enforcement to be concerted by voluntary certification systems as is the case for the EU Renewable Energy Directive for biofuels and bioliquids for transportation (2009/28//EC). See also Flach et al. (2012).

[b] Laws regulating air quality (emission of nitrogen, sulphur, particles etc.) might however apply.

While Tables 5 and 6 clearly demonstrate the complexity of actors involved and the multiple levels of governance affecting, for example, the flow of woody biomass to produce electricity with wood pellets in Europe, recent work has also highlighted the complexity of systems operating within any one cell of Table 6 (Stupak et al. 2007, Stupak et al. 2011; Van Dam et al. 2010). These authors have shown that there are more than 50 certification systems of relevance to the bioenergy sector. Hence, governance is increasingly complex, with the potential for negative impacts along the whole supply chain and overlapping jurisdictions at any one point in the supply chain. There is concern that, as a result, trade may be restricted and that individual actors may be unnecessarily “over-regulated”, with excessive costs along the supply chain. The rapid global proliferation of a variety of certification systems means that there is now a significant diversity of approaches to standards, and a diversity of approaches to assessments (audits and reporting), potentially resulting in consumer confusion, unintended negative impacts for trade, and, not surprisingly, the potential failure to achieve sustainability goals. This situation has led to some asking if there might be beneficial outcomes of checking and adjusting for consistency among the multiple levels of governance currently operating, and if systems might beneficially be harmonized, for example by establishing internationally agreed meta-standards (Van Dam et al. 2010). There is thus an urgent need for careful coordination among all key parties to move the sector ahead.

## 9.0 CONCLUSIONS

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. The interactions among social, economic and environmental values are strong. Wood-based bioenergy production and use can have a mix of positive and negative outcomes at local and system levels. Communities, businesses, and nations engaged in strategic planning for bioenergy development should anticipate the need to balance expected costs with benefits and should conduct trade-off analyses to find solutions that satisfy a range of stakeholders.

The economic value of the activity must be apparent before investments in biomass production, supply and conversion machinery, plants and other infrastructure will effectively occur. The plethora of (sometimes conflicting) support measures, potential policy shifts, overlapping laws and regulations, and competing certification schemes add significant uncertainties and costs when considering investments in the biomass supply chain.

Intelligent siting and sizing of a bioenergy project is the most important key to economic sustainability: the availability of affordable forest biomass and absence of easily accessible competing fuels creates a competitive advantage for biomass in energy production. It is equally important that all energy produced can be sold to markets. This means that heat, steam and electricity produced from biomass are truly in demand and have real market value.

The importance of economic sustainability has to be emphasized in international and national policies, roadmaps and programs for bioenergy development. It has to be present also in practice, when investments and operations are planned and executed. It is evident that when economic sustainability is not present in the bioenergy value chain, profit is not gained and the operation eventually shuts down. Economic sustainability is therefore necessary for added value creation and to properly ensure other dimensions of sustainability.

# REFERENCES

Aguilar, F., Gaston, C., Hartkamp, R., Mabee, W., Skog, K. 2011a. Wood energy markets, in Clark, D. (eds.) Forest products annual market review 2010-2011. Geneva Timber and Forest Study Paper 27. UNECE/FAO. 174 p.

Aguilar, F., Song, N., Shifley, S. 2011b. Review of consumption trends and public policies promoting woody biomass as an energy feedstock in the U.S. Biomass and Bioenergy 35 (2011) 3708-3718.

Ahn H. and Dyckhoff H. 1997. Organisatorische Effektivität und Effizienz. In: WiSt – Wirtschaftliches Studium, 26. Jg., H. 1 p. 2–6. (In German).

Alakangas, E. 2000. Suomessa käytettävien polttoaineiden ominaisuuksia (Properties of fuels used in Finland). Technical research centre of Finland . VTT research notes 2045. Helsinki. 172 s. + app.

Alakangas, E & Flyktman, M. 2001. Biomass CHP technologies. VTT Energy reports 7/2001. Jyväskylä. Finland. Avalable: http://www.vtt.fi/inf/julkaisut/muut/2001/ENE_Alakangas.pdf

Alakangas, E., Vesterinen, P. & Martikainen, A. 2011. Summary of the legal and technical requirements of biomass and bioenergy in 18 EU countries. EUBIONET III project report. Available: http://www.eubionet.net/GetItem.asp?item=digistorefile;308261;1770&params=open;gallery

Andersson, G., Asikainen, A., Björheden, R., Hall, P., Hudson, J., Jirjis, R., Mead, D., Nurmi, J., Weetman, G. 2002. Production of forest energy. In: Richardson, J., Börheden, R., Hakkila, P., Lowe, A.T., Smith, C.T. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston. Pp. 49-123.

Anon.2008. Mobilisation and efficient use of wood and wood residues for energy generation. Report to the Standing Forestry Committee. http://ec.europa.eu/agriculture/fore/publi/sfc_wgii_final_report_072008_en.pdf

Asikainen, A., Laitila, J., Ranta, T. 2001. Hakkuutähdehakkeen kustannustekijät ja suurimittakaavaisen hankinnan logistiikka. Julkaisussa: Alakangas, E. (toim.). Puuenergian teknologiaohjelman vuosikirja. Jyväskylä, 5.-6.9.2001. VTT Symposium 216: 47-60 (in finnish).

Asikainen, A., Björheden, R., Nousiainen, I. 2002. Costs of wood energy. In: Richardson, J., Börheden, R., Hakkila, P., Lowe, A.T., Smith, C.T. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston. p. 125-157

Asikainen, A. (convening lead author), Anttila, P., Heinimö, J., Smith, T., Stupak, I. & Ferreira Quirino, W. 2010. Forests and bioenergy production. In: Mery, G., Katila, P., Galloway, G., Alfaro, R.I., Kanninen, M., Lobovikov, M. & Varjo, J. (eds.). Forests and Society - Responding to Global Drivers of Change. IUFRO World Series 25: 183-200. ISBN 978-3-901347-93-1

Asikainen, A. Raw material resources. 2011. In: Alén, R. (eds. ) 2011. Biorefining of forest resources. Papermaking science and technology. Book 20. Paper Engineer`s association. Porvoo. Finland. 380 p.

Asikainen, A., Röser, D., Laitila, J., Sikanen, L. 2011. Feasibility of the Nordic forest energy harvesting technology in Poland and Scotland. Biomass & Bioenergy 35. p. 4565-4569.

Biomass Research and Development Board (BRDB). 2008.The Economics of Biomass Feedstocks in the United States: A Review of the Literature. Occasional Paper No. 1, Biomass Research and Development Board. http://www.usbiomassboard.gov/pdfs/7_

Bird, N., Cowie, A. Cherunini, F. and Jungmeier, G. 2011. Using a LCA approach to estimate the net GHG emissions of bioenergy. IEA Bioenergy: ExCo:2011:03. 20 pp.

Bloomberg New Energy Finance. 2011.Global trends in clean energy investments. Available: https://www.bnef.com/Presentations/download/84

Bloomberg New Energy Finance. 2012. Global trends in renewable energy investments. Available: http://fs-unep-centre.org/sites/default/files/publications/globaltrendsreport2012final.pdf

Borsboom, N., Hektor, B., McCallum, B. & Remedio, E. 2002. Social implications of forest energy production, in Richardson, J., Börheden, R., Hakkila, P., Lowe, A.T., Smith, C.T,. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers.Dordrecht. Boston. Pp. 49-123.

BP. 2011. Statistical review of World Energy June 2011. 46 p.

Brunberg, B., Andersson, G., Norden, B. & Thor, M. 1998. Forest bioenergy fuel – final report of commissioned project. The Forestry research Institute of Sweden, Uppsala, Sweden. 58 pp.

Brunner, T., Obernberger, I.& Biedermann, F. 2012. Particulate matter emissions from small-scale biomass combustion systems – characteristics and primary masures for emission reduction. IEA Bioenergy Conference 2012 Proceedings.pp.175-182.

Buchholz,T., Luzadis, V.& Volk, T. 2009. Sustainability criteria for bioenergy systems: results from an expert survey, Journal of Cleaner Production, Vol. 17, Supplement 1. p. S86-S98

Burger, J.A. 2002. Soil and long-term site productivity values. pp. 165-189. In: Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston.

Buytaert, V., B. Muys, N. Devriendt, L. Pelkmans, J.G. Kretzschmar, R. Samson. Towards integrated sustainability assessment for energetic use of biomass: A state of the art evaluation of assessment tools. Renewable and Sustainable Energy Reviews 15 (2011) 3918–3933.

C.A.R.M.E.N . 2011. http://www.carmen-ev.de/en/index.html

Caputo,A, Palumbo,M., Pelagagge,P., Scacchia,F. 2005. Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass and Bioenergy, Vol. 28, Issue 1. p. 35-51

Doane, D. & MacGillivray, A. 2001. Economic sustainability - The business of staying business. The Sigma project. New Economics Foundation & ACCA, Lontoo. http://projectsigma.co.uk/RnDStreams/RD_economic_sustain.pdf

ET Bioenergy. 2005. Country Report: Finland. WP1.

EurObserv.ER. 2011. Solid biomass Barometer. Systemes solaires. Le journal des énergies renouvelables. No. 206. November 2011. 20 p.

European Commission. 2008. Combating climate change The EU leads the way. Europe on the move series 24 p.

European Economic Forecast. 2011. Comission staff working document 1/2011. http://ec.europa.eu/economy_finance/publications/european_economy/2011/pdf/ee-2011-1_en.pdf

Faber, J., Bergsma, G., Vroonhof, J. 2005. Bioenergy in Europe, Policy trends and issues. CE. Delft. The Netherlands. 64 p.

FAO. Criteria and indicators for sustainable woodfuels. 2010. FAO Forestry Paper No. 160. Rome. 93 p.

Fagernäs, L., Johansson, A., Wilén, C., Sipilä, K., Mäkinen, T., Helynen, S., Daugherty,E., den Uil, H., Vehlow, J., Kåberger, T. & Rogulska, M. 2006. Bioenergy in Europe. Opportunities and Barriers. Research Notes 2352. Espoo.118 p.

Flach B., Bendz, K., Lieberz, S. 2012. Biofuels Annual, EU Biofuels Annual 2012. GAIN report NL2020, 34 pp.

Florin, M. & Bunting, C. 2009. Risk governance guidelines for bioenergy policies. Journal of Cleaner Production. Vol 17. Supplement 1. p S106-S108

Franck, J. 2008. Business risk management. Atlantic International University:Honolulu. Hawaii. http://www.aiu.edu/publications/student/english/Business%20Risk%20Management.html

Freer-Smith,P. 2007. Environmental change and the sustainability of European Forests. Journal of Sustainable Forestry. Vol 24, no 2. pp. 165-187.

Fritsche, Uwe R. Klaus J. Hennenberg, Kirsten Wiegeman, Rocio Herrera, Bernd Franke, Susanne Köppen, Guido Reinhardt, Veronika Dornburg, André Faaij, Edward Smeets. Bioenergy Environmental Impact Analysis (BIAS): Analytical Framework, FAO Environmental and Natural Resources Service Series, No. 46 – FAO, Rome, 2010

FSC. 2004. Forest Stewardship. FSC Canada. National Boreal Standard. http://www.fsccanada.org/borealstandard.htm. Accessed 5 April 2012.

Gan, J., C. Hanson, B. Lattimore, G.B.M. Pedroli, E.M. Remedio, and C.T. Smith . Socio-economic benefits and challenges. Chapter 13. In: Biofuels in Practice: Technological, Socio-economical and Sustainability Perspectives. Edited by Luc Van Ginneken and Luc Pelkmans. Series in Advanced Topics in Environmental Science. ILM Publications. December 2012. ISBN: 9781906799113.

Gan,J & Smith,C.T. 2006. A comparative analysis of woody biomass and coal for electricity generation under various $CO_2$ emission reductions and taxes. Biomass and Bioenergy, Vol. 30. Issue 4. p. 296-303.

Gan, J. and C.T. Smith. 2010. Integrating biomass and carbon values with soil productivity loss in determining forest residue removals. *Biofuels* 1(4): 539–546.

Hakkila, P., Nousiainen, I. & Kalaja, H. 2001. Use of forest chips in Finland. Position paper for 1999. VTT research notes 2087. Espoo. 37 s.

Hakkila, P. 2002. Operations with reduced environmental impact. In: Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston. pp. 244-261.

Hakkila, P. 2004. Developing technology for large-scale production of forest chips Wood Energy Technology Programme 1999–2003. Final report. Technology programme report 6/2004. 98 p.

Hakonen, T. & Laurila, J. 2011. Metsähakkeen kosteuden vaikutus polton ja kaukokuljetuksen kannattavuuteen. Seinäjoen ammattikorkeakoulun julkaisuja B55. 31 p.

Hardisty, P. E. 2010. Environmental and economic sustainability. Environmental and ecological risk assesment. Virginia Institu of Marine Science. Gloucester Point. Virginia. 315 p.

Heikkilä, J., Sirén, M., Ahtikoski, A., Hynynen, J., Sauvula, T. & Lehtonen, M. 2009. Energy wood thinning as a part of the stand management of Scots pine and Norway spruce. Silva Fennica 43(1): 129–146.

Heiskanen, V-P & Flyktman, M. 2005. Feasibility study of the boiler retrofit at Elektrocieplownia power plant. VTT Processes. Research Report. 21 p.

Helmisaari H-S., Hanssen, K., Jacobson, S., Kukkola, M., Luiro, J., Saarsalmi, A., Tamminen, P.& Tveite B. 2011. Logging residue removal after thinning in Nordic boreal forests: Long-term impact on tree growth. Forest Ecology and Management, Volume 261, Issue 11. Pages 1919-1927

Hetemäki, L. 2008. Puu energiaksi vai paperiksi? Bioenergia 6/2008: 9-11.

Hill, C. 2011. An introduction to sustainable resource use. Earthscan, London. 225 p.

Hillring, B. 2006. World trade in forest products and wood fuel. Biomass and Bioenergy 30 (2006) 815-825.

Hogan, M., Otterstedt, J., Morin, R. & Wilde, J. (Eds.). 2010. Biomass for Heat and Power. Opportunity and economics. European Commission . Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. 72 p.

Hubbard, W.L., Biles, C., Mayfield, S.A. (eds.). 2007. Sustainable forestry for bioenergy and bio-based products. Trainers curriculum notebook. Southern Forest Research Partnership Inc. Athens, Georgia. 150 s.

Hutchins, M. & Sutherland, J. 2008. An exploration of measures of social sustainability and their application to supply chain decisions, Journal of Cleaner Production, Vol. 16, Issue 15. p. 1688-1698

ICE. 2011.Market data. https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=83

IEA.2011. CO2 Emissions from Fuel Combustion. Highlights. Available: http://www.iea.org/co2highlights/co2highlights.pdf

IEA.2012. Key world energy statistics. Available: http://www.iea.org/publications/freepublications/publication/kwes.pdf

Jack,M. 2009. Scaling laws and technology development strategies for biorefineries and bioenergy plants. Bioresource Technology. Vol.100, Issue 24. Pp. 6324-6330

Jirjis,R. 1995. Storage and drying of wood fuel, Biomass and Bioenergy, Vol. 9, Issues 1-5, p. 181-190

Junginger, M.H., Lamers, P., Heinimö, J., Cocchi, M. 2012. Global solid and liquid biomass trade for energy – an overview. IEA Bioenergy Conference 2012 Proceedings. pp. 131-136.

Junginger, M., Bolkesjø, T., Bradley, D., Dolzan, P., Faaij, A., Heinimö, J. Hektor, B., Leistad, Ø., Ling, E., Perry, M., Piacente, E., Rosillo-Calle, F., Ryckmans, Y., Schouwenberg, P., Solberg, B., Trømborg, E., da Silva Walter, A., de Wit, M. 2008. Developments in international bioenergy trade. Biomass and Bioenergy 32 (2008) 717 – 729.

Jylhä, P., Dahl, O., Laitila, J. & Kärhä, K. 2010. The effect of supply system on the wood paying capability of a kraft pulp mill using Scots pine harvested from first thinnings. Silva Fennica 44(4): 695–714.

Kallio, M., Anttila,P., McCormick,M. & Asikainen, A. 2011. Are the Finnish targets for the energy use of forest chips realistic—Assessment with a spatial market model. Journal of Forest Economics. Vol. 17. Issue 2. p. 110-126

Karjalainen, T., Asikainen, A., Ilavsky, J., Zamboni, R., Hotari, K-E & Röser, D. 2004.Estimation of energy wood potential in Europe.Working papers of Finnish forest research institute 6. 43 p.

Kranzl, L., Matzenberger, J., Junginger, M. & Tromborg, E. 2012. Potential future developments of international bioenergy trade. IEA Bioenergy Conference 2012 Proceedings. pp. 131-136.

Karttunen, K., Jäppinen, E., Väätäinen, K. & Ranta, T. Metsäpolttoaineiden vesitiekuljetus proomukalustolla. Lappeenrannan teknillinen yliopisto, Teknillinen tiedekunta, Energia- ja ympäristötekniikan osasto, Bioenergiatekniikka, Mikkeli 2008 54 p.

Kittler, B., W. Price, W. McDow and B. Larson. 2012. Pathways to Sustainability. Environmental Defense Fund. 54 pp. Available on line at www.edf.org/bioenergy.

Kluender, R., D. Lortz, W. McCoy, B. Stokes, and J. Klepac. 1998. Removal intensity and tree size effects on harvesting cost and profitability. Forest Products Journal 48(1):54-59.

Kuitunen, K., Räsänen, P., Mikkola, M. & Kuivanen, R. 1999. Kehittyvä yritysverkosto. Toimittajaverkostot kilpailukyvyn ja osaamisen lähteenä [Developing enterprise network. Supplier networks as a source of compete tiveness and knowledge]. Technical Research Centre of Finland, VTT Tiedotteita – Meddelanden – Research Notes 1976. 148 p.

Kumar, A., Cameron, J & Flynn, P. 2003. Biomass power cost and optimum plant size in western Canada. Biomass and Bioenergy, Vol. 24. Issue 6. p. 445 – 464

Laitila, J., Heikkilä, J. & Anttila, P. 2010. Harvesting alternatives, accumulation and procurement cost of small-diameter thinning wood for fuel in Central Finland. Silva Fennica vol. 44 No 3. p. 465–480.

Laitila, J. 2012. Methodology for choice of harvesting system for energy wood from early thinning. Doctoral thesis. University of Eastern Finland. Dissertationes Forestales 143. 68 p.

Lamers, P., Junginger, M., Marchal, D., Schouwenberg, P., Cocchi, M. 2011. Global wood chip trade for energy. IEA Bioenergy Task 40

Lattimore, B., C.T. Smith, B.D. Titus, I, Stupak, G. Egnell. 2009. Environmental factors in woodfuel production: risks, and criteria and indicators for sustainable practices. *Biomass & Bioenergy* 33(10): 1321-1342.

Leinonen, A. 2004. Harvesting Technology of Forest residues for fuel in the USA and Finland. Espoo. VTT Tiedotteita . Research Notes 2229. 132 p. + app. 10 p.

Lunnan, A., Vilkriste, L., Wihelmsen, G., Mizaraite, D., Asikainen, A., and Röser, D. 2008. Policy and economy aspects of forest energy utilization, in Röser, D., Asikainen, A., Raulund-Rasmussen and Stupak, I. (eds.) 2008. Sustainable use of forest biomass for energy, A synthesis with focus on the baltic and Nortic region. Managing Forest Ecosystems 12. pp.197-234

Mayfield, C.; C. Smith; B. Lattimore. 2007. Using the Adaptive Forest Management Planning Framework to Achieve Sustainable Bioenergy Production. In: Hubbard, W.; L. Biles; C. Mayfield; S. Ashton

(Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. Pages 239–242.

McKechnie, J., S. Colombo, J. Chen, W. Mabee & H. MacLean. 2011. Forest carbon or forest bioenergy? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels. Environmental Science & Technology (45): 789 – 795.

McKenzie, K.J., Sershun, N. 2010. Taxation and R&D: An Investigation of Pushand Pull Effects. Canadian Public Policy, Volume 36, Number 3 p. 307-324

McNeel, J., Wang, J., Wu, J., Goff ,T. 2008. Woody biomass sustainability for bioenergy production in west Virginia. National Center for Food and Agricultural Policy. Bio-Energy Awareness Days 2nd Grand Challenges. http://www.ncfap.org/documents/BEADII/WVUBiomassGChallengeBEADII.pdf.

Mead, D.J. and C.T. Smith. 2012. Principles of nutrient management for sustainable forest bioenergy production. WIREs Energy Environ 2012, 1: 152–164 doi: 10.1002/wene.3

Montreal Process Working Group. 2005. The Montreal Process (website). www.rinya.maff.go.jp/mpci/.

Nurmi, J. 1999. The storage of logging residue for fuel, Biomass and Bioenergy, Vol. 17, Issue 1, p. 41-47

Nurmi, J. 2007. Recovery of logging residues for energy from spruce (*Pices abies*) dominated stands. Biomass and Bioenergy 31: 375–380.

Olsson, O. 2012. Wood fuel markets in the Northern Europe. Price Formation and Internationalization. Doctoral thesis. Swedish University of Agricultural Sciences Skinnskatteberg. Uppsala. 77 p.

Pfeiffer, K. 1967. Analysis of methods of studying operational efficiency in forestry. University of British Columbia, Canada. 94 p.

Pingoud, K. & Forsström, J. 2009. Forest-based bioenergy and its climatic and economic viability - an integrated analysis (FOBIT). Technical Research Centre of Finland. Conference presentation. Sustainable Energy Programme, Helsinki, October 6-7, 2009. http://www.aka.fi/Tiedostot/Tiedostot/ENERGIA/Vuosiseminaari%202009/Kim%20Pingoud_FOBIT.pdf

Pulkki, R. 2012. Cut-to-length, tree-length or full tree harvesting? Lecture material. Lakehead University. Faculty of forestry. Canada. Avalaible: http://flash.lakeheadu.ca/~repulkki/ctl_ft.html

Pöyry Forest Industry Consulting Oy. 2006. Metsäenergian tuotannon, korjuun ja käytön kustannustehokkuus sekä tukijärjestelmän vaikuttavuus päästökaupan olosuhteissa. Maa- ja metsätalousministeriö. Loppuraportti 9.8.2006.

Ranta, T. 2005. Logging residues from regeneration fellings for biofuel production – a GIS-based availability analysis in Finland. Biomass and Bioenergy 28. p.171–182.

Ranta, T., Korpinen, O-J., Jäppinen,E., Karttunen, K. 2012. Forest Biomass Availability Analysis and Large-Scale Supply Options. Open Journal of Forestry 2012. Vol.2, No.1, p. 33-40

Ranta, T., Lahtinen, Elo, P. J., Laitila J. 2007. The effect of CO2 emission trade on the wood fuel market in Finland. Biomass and Bioenergy 31. p 535–542.

Ranta, T., Lahtinen, P., Laitila, J. 2005. The regional balance of wood fuel demand and supply in Finland. In: Asplund, D. (ed.). Bioenergy in Wood Industry 2005, 12.-15.9.2005 - Book of Proceedings. FINBIO Publications 32. p. 39-45

Raulund-Rasmussen K, Stupak I, Clarke N, Callesen I, Helmisaari H-S, Karltun E, Varnagiryte-Kabasinskiene I (2008) Chapter 3. Effects of very intensive forest biomass harvesting on short and long term site productivity. In: Röser D, Asikainen A, Raulund-Rasmussen K, Stupak *I* (eds.) (2008) Sustainable Use of Forest Biomass for Energy. A Synthesis with Focus on the Baltic and Nordic Region. Springer, Managing Forest Ecosystems, 12:29-78.

Reichling, J.P.& Kulacki, F.A. 2011. Comparative analysis of Fischer–Tropsch and integrated gasification combined cycle biomass utilization. Energy, Vol. 36. Issue 11. p. 6529-6535

REN. 2012. Renewables Global Status Report 2012. Paris: REN 21 Secretariat. 82 p. Available: http://www.ren21.net/Portals/97/documents/GSR/GSR2012_low%20res_FINAL.pdf

Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T,. (eds.) 2002. Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston.

Richardson, J. 2002. Framework for conventional forestry systems for sustainable production of bioenergy, in Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T,. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston. Pp. 49-123.

Roos, A. 2002. Policy and institutional factors affecting forest energy, in Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T,. (eds.) Bioenergy from sustainable forestry – Guiding principles and practice. Kluwer Academic Publishers. Dordrecht. Boston. Pp. 299-320.

Röser, D. 2012. Operational efficiency of forest energy supply chains in different operational environments. Doctoral thesis. University of Eastern Finland. Dissertationes Forestales 146. 83 p.

Skogsstatistisk årsbok 2011. Skogsstyrelsen. Sveriges officiella statistisk. 385 s.

Skog, K., Barbour, J., Abt, K., Bilek, E., Burch, F., Fight, R., Hugget, R., Miles, P., Reinhardt, E., Shepperd, W. 2006. Evaluation of silvicultural treatments and biomass use for reducing fire hazard in western states. Research Paper FPL-RP-634. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Stupak I, Asikainen A, Jonsell M, Karltun E, Lunnan A, Mizarete D, Pasanen K, et al. 2007. Sustainable utilisation of forest biomass for energy - possibilities and problems, policy, legislation, certification and recommendations in the Nordic, Baltic and other European countries. Biomass & Bioenergy 31: 666-684. doi:10.1016/j.biombioe.2007.06.012

Stupak, I., Asikainen, A., Röser, D., Pasanen, K. Review of recommendations for forest energy harvesting and wood ash recycling. Teoksessa Röser, D., Asikainen, A., Raulund-Rasmussen and Stupak, I. (eds.) 2008. Sustainable use of forest biomass for energy, A synthesis with focus on the baltic and Nortic region. Managing Forest Ecosystems 12. p. 155-196.

Stupak, I., B. Lattimore, B.D. Titus, C.T. Smith. 2011. Criteria and indicators for sustainable forest fuel production and harvesting: a review of current standards for sustainable forest management. Biomass &Bioenergy 35 (8): 3287-3308.

Sundberg U. and Silversides C.R. 1988. Operational Efficiency in Forestry. Volume 1: Analysis. Forestry Sciences. Kluwer Academic Publishers. The Netherlands. 219 p.

Thornley, P and Cooper, D (2008). The effectiveness of policy instruments in promoting bioenergy. Biomass and Bioenergy. 32 (10): 903-913

Thörnqvist, T. and Jirjis, R. 1990. Bränsleflisens förändring över tiden vid lagring i stora stackar. (Changes in fuel chips during storage in large piles). Swedish University of Agricultural Sciences, Uppsala, Sweden. Department of Forest Products. Report No. 219.

Trädbränsle- och torvpriser, Nr 4/2011. 01.12.2011. Sveriges officiella statistik Statistiska meddelanden en 0307 SM 1104. 2 s.

Tuerk, A., Cowie, A. & Leopold, A. 2011. The influence of Emissions Trading Schemes on bioenergy use. IEA Bioenergy. Task 38 - Greenhouse Gas Balances of Biomass and Bioenergy Systems. Available: http://www.ieabioenergy-task38.org/publications/T38_ETS_Bioenergy_2011.pdf

USDA-Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western States. Gen. Tech. Rep. RMRS-GTR-149. Fort Collins, CO: U.S. Department of agriculture, Forest Service, Rocky Mountain Research Station.

USDA-Department of Agriculture. 2006. Farm bill theme paper : Energy and agriculture 2007. Available: http://www.usda.gov/documents/Farmbill07energy.pdf.

UNECE .2011. Interactive database. http://www.unece.org/forests/fpm/31stmeeting.html

U.S. Department of Energy. 2012. Renewable electricity production tax credit (PTC). Available: http://energy.gov/savings/renewable-electricity-production-tax-credit-ptc

Valsta, L. & Häggblom, R. 2009. Wood markets and the cost of wood, in Kellomäki, S. (eds). 2009. Forest Recources and Sustainable Management. Papermaking science and technology. Book 2. Paper Engineer`s association. Porvoo. Finland. 572 p.

van Dam, J., M. Junginger, A.P.C. Faaij. 2010. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renewable and Sustainable Energy Reviews 14( 9): 2445-2472.

Vogt, K., Andreu, M.G., Vogt D.J., Sigurdardottir, R., Edmonds, R.L., Schiess, P. & Hodgson, K. 2005. Societal values and economic return added for forest owners by linking forests to bioenergy production. Journal of Forestry 103:21-27.

World Bank 2010. Environmental Assessment Sourcebook and Updates. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTENVASS/0,,contentMDK:20482380~menuPK:1182640~pagePK:148956~piPK:216618~theSitePK:407988,00.html

World Commission on Environment and Development. 1987. Our Common Future. Report of the World Commission on Environment and Development. Published as Annex to General Assembly document A/42/427. Available: http://www.un-documents.net/our-common-future.pdf

# ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Dr Bruce Talbot, Dr Ger Devlin, Dr Marilyn Buford and other IEA Bioenergy Task 43 national team leaders and collaborators for their support and comments on the report. Jamie Joudrey served as Consultant Editor and provided valuable input in finalising the manuscript. All these contributors are gratefully acknowledged.

IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, USA.

## Further Information

Task 43
Website www.ieabioenergytask43.org
Göran Berndes – Task leader
Email: goran.berndes@chalmers.se
Tat Smith – Associate Task Leader
Email: tat.smith@utoronto.ca

IEA Bioenergy Secretariat
Website: www.ieabioenergy.com
John Tustin – Secretary
Email: jrtustin@xtra.co.nz
Arthur Wellinger – Technical Coordinator
Email: arthur.wellinger@novaenergie.ch