What Science Can Tell Us

Forest Bioenergy for Europe

Paavo Pelkonen, Mika Mustonen, Antti Asikainen, Gustaf Egnell, Promode Kant, Sylvain Leduc and Davide Pettenella (editors)

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Foreword

The theme of this report, forest bioenergy, focuses on an issue that has historically been one of the oldest and most lasting uses of forests by humans. Even today, over 50% of the world's wood consumption and some 20% in Europe is related to wood fuel (FAOSTAT). However, these simple percentages hide the fact that wood fuel or forest bioenergy can be a thousand different things, as also revealed by this report. Neither do these percentages give a full picture of the magnitude of forest bioenergy. For example, the statistics do not take into account the forest industry's side streams and post consumer wood usage for energy, therefore underestimating the scope of the phenomenon.

The importance of forest bioenergy in Europe has heightened this century thanks to the European Union's renewable energy policy and its climate change mitigation objectives, in particular. Moreover, energy security issues, rural policies as well as income and employment generation related to bioenergy production have all played important roles.

Forest bioenergy is a renewable energy source that can replace fossil fuels. But its increasing use may also have unwanted impacts such as the loss of biodiversity, the use of inefficient energy technologies, and being questionable in terms of economic viability. If forest bioenergy is supported by misguided government policies, it may also create market distortions with unwanted impacts to other industries. How sound or unsound forest bioenergy is in these respects depends on many factors. There is no generally applicable answer. Forest bioenergy can make perfect environmental and economic sense, or not. It depends on the particular circumstances.

The above points seek to illustrate how forest bioenergy is a multifaceted and complex issue. Exactly because of this, there is a continuous need for evidence-based information that helps better understand the many-sided opportunities and impacts of forest bioenergy in Europe. Moreover, this can help direct forest bioenergy along environmentally and economically efficient routes while avoiding unwanted detours. This report helps to address these needs and at the same time provide valuable insights into this complex issue.

The study was carried out by a group of experts from 12 countries representing 28 institutes. I would like to congratulate the editors for producing a very readable and insightful synthesis on a challenging topic, and for coordinating and guiding such a large group of authors who have themselves earned acknowledgment for their valuable work.

I would also like to thank Veli Pohjonen and Ronald Steenblick for reviewing the manuscript and providing constructive comments and suggestions.

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We wish you interesting and valuable reading,

Lauri Hetemäki
Editor-in-Chief, What Science Can Tell Us series

Introduction

Paavo Pelkonen and Promode Kant

Increased use of renewable energy constitutes an important part of the global efforts to reduce greenhouse gas emissions. The United Nations Conference on the Human Environment, held in Stockholm in 1972, proclaimed that man with his power to 'transform the environment in countless ways and on an unprecedented scale' is both a 'creature and moulder of his environment' and laid down the principle that 'the capacity of the earth to produce vital renewable resources must be maintained and, wherever practicable, restored or improved'. Two decades later, the United Nations Framework Convention on Climate Change (UNFCCC) acknowledged that the largest share of historical and current global emissions of greenhouse gases originated in the ever increasing use of fossil fuels in developed countries and encouraged the developed countries and their regional economic integration organizations like the European Union (EU) to adopt policies and measures that would demonstrate their lead in developing sustainable renewable energy technologies. Expectations of energy security, together with the urgent need for sustainable energy consumption have also been important driving factors behind the expanding role of renewable energy.

Available data suggest that biomass provides about 10–15% of the global total primary energy supply, of which 60% is used in traditional households mostly in developing countries, some 25% for heat and power generation largely in developed countries, and the remaining in informal sectors such as charcoal and brick making, almost entirely in developing countries.The global bioenergy technology roadmap for heat and electricity generation prepared by the International Energy Agency (IEA)[1] in 2012 sees high promise with the global annual total primary bioenergy supply growing manifold from 50 EJ today to 160 EJ in 2050 requiring 5–7 billion tonnes of dry biomass. Similar growing trends of demand have been presented in several studies for Europe. Many sources of bioenergy may remain costly relative to fossil energy for up to 20 years from today; gradually tapering fiscal measures to bridge this cost gap would thus continue to be needed during this long transitional phase, even as attempts at increasing cost competitiveness are strengthened. Technically, while there is high potential of enhancing the use of biomass for energy generation, sustainability aspects, such as the concerns for food security, and environmental and equity considerations, combined with cheaper and greater access to new non-renewable sources of energy in many regions of the world, would limit the actual achievement.

1 IEA 2012. Technology Roadmaps. Bioenergy for Heat and Power.

The chapters that follow in this book discuss many of the critical issues involved in using biomass for producing renewable energy in the European Union. Chapter 1 presents an overview of the use of wood and wood waste for energy production in the EU that has been increasing consistently and is currently assessed to constitute almost one half of the total renewable energy of about 7,077 petajoules (10% of gross inland energy consumption) for the entire EU, although the picture differs widely across countries. The challenges in assessing forest biomass supply and demand within and outside the EU and the increase in biomass trade has been examined. The facilitation of biomass trade would be needed to respond, for instance, to local supply and the demand imbalances that would be expected in biomass consumption of this magnitude. This would also help to make bioenergy more price-competitive, which varies greatly across regions. The optimization of price-competitiveness, with respect to location dependent costs and production factors, is needed for decision making in the energy sector.

Of all forms of renewable energy, bioenergy is easily the most versatile that can be converted to solid, liquid, gaseous states, and as electricity, enabling its carriage to end consumers through the existing energy supply networks. The authors of Chapter 2 analyze the most promising forest biomass related conversion opportunities. Presently, almost half of biomass based energy as a fraction of the total final use of energy is solid wood used mainly in the heating sector across Europe. The chapter presents conversion technologies that are common across the globe and also new and challenging avenues for research, development and innovation everywhere.

Forests form the largest source of biomass, which comes from stems, branches, stumps and roots in the form of chips, billets, sawdust, bark, and other wood wastes with varying calorific values, moisture and ash contents depending on the mix of tree species forming the source. Much of this originates in (i) logging residues from final and intermediate harvestings, including silvicultural thinning and salvage logging of dead and diseased trees; (ii) industrial residues such as sawdust, bark and black liquor from paper manufacture; (iii) forest growth that is silviculturally available but is not in demand for other usage; and (iv) dedicated short rotation plantations for energy. These resources become available when their opportunity and transportation costs are favourable for energy production, and the negative consequences for biodiversity conservation, soil fertility and local usage are acceptable. The above mentioned steps of the forest biomass-based energy value chain are discussed in Chapters 3 and 4 from the point of view of sustainable production and the supply of forest resources.

The fundamental questions of sustainability are discussed in detail in Chapter 5. More than 10 million ha of set-aside fields are presently available in the EU for the cultivation of dedicated biomass tree crops. Cultivation of this and possible other suitable land areas needs appropriate policies that reward short rotation tree cultivation for bioenergy. The needed large-scale land-use changes in existing forests and possible plantations are generating discussions rooted in ethics and commerce among various interest groups from farmers' unions to environmental non-governmental organizations across Europe as discussed in Chapters 4 and 5. The recent economic downturn and the resulting political uncertainties are further adding to this debate by attempting to redefine the concept of sustainability.

The climate mitigation value of replacing fossil fuels with the solar radiation reaching the earth now and stored in biomass through the process of photosynthesis is obvious.

But an assertion often made of the climate neutrality of bioenergy is an overstatement made under the assumption that the CO_2 emitted in its use would be sequestered back if the land from which biomass is sourced remains available. This, however, does not factor the time difference between the emission and recapture of the CO_2 in vegetation. Nor does it usually account for the CO_2, CH_4 and N_2O released in raising, maintaining and harvesting the biomass, and in its processing and delivery to the consumer. A major challenge in the use of bioenergy is keeping close account of its true mitigation value, particularly when sourced from countries with inadequate standards of monitoring, reporting and the verification of relevant data. Regardless, with or without the bioenergy market, every forest owner – both public and private – must be aware and understand their silvicutural responsibility to maintain and even increase forest areas and forest growth for meeting the biomass and ecosystem demands and opportunities of various ecosystem services in order to meet future generations.

EU policy on renewable energy

As discussed by many authors of this report, a long-term policy framework on renewable energy is critical to enhancing investors' confidence by reducing uncertainties that deter the private sector from investing in new technologies. Directive 2009/28/EC of the European Union on the promotion of the use of energy from renewable sources is a comprehensive work of legislation aimed at achieving a composite 20% share for renewable energy in the European final consumption of energy by 2020. For this purpose, challenging mandatory national renewable energy targets have been set on the basis of existing levels of achievements of the member countries. The new European Commission proposal for the 2030 climate and energy goals for a competitive, secure and low-carbon EU economy shows a strong commitment to develop a long-term policy framework (published January 22, 2014). The recently introduced long-term policy would reduce uncertainties and encourage investments in modern conversion units such as Fortum's new pyrolysis process-based bio-oil plant or UPM's crude tall oil production-based biodiesel (UPM BioVerno) plant in Finland, among others.

The EU directives have taken several key steps to address sustainability both within Europe and beyond where the impact of European policies is the highest. Its geographical coverage is unique in that it covers the sources of renewable energy feedstock, irrespective of their location, reaching extensively into production, processing, transportation and distribution for establishing sustainability throughout the value chain (see Chapters 1 and 5).

An important objective of the European bioenergy policy has been the decentralisation of renewable energy production leading to the increased utilisation of local energy sources, improved local energy security, shorter transport distances and lowered transmission losses. Decentralisation is also expected to meet a central political objective of the Union that aims at creating an environment in which local and regional entrepreneurs are encouraged to make use of this economic opportunity for generating profits and creating jobs (see Chapters 1, 3 and 5).

National innovativeness for joint targets

Gradually increasing mandatory national targets have been essential in creating a degree of certainty for investors and encouraging the continuous development of technologies to generate energy from all types of renewable sources. This would also need identification and development of new and more wood resources both within and outside the European Union. The new European Commission proposal for the 2030 climate and energy goals for a competitive, secure and low-carbon EU economy removes the national mandatory targets and regulations, giving opportunities for markets driven development. According to the new policy, the Member States need to sustainably mobilize existing and develop new forest resources according to the best practices by mapping their own forest biomass territory. By exploiting the full potential of biomass sustainably and efficiently, the Member States will have good opportunities to meet the joint renewable energy target of the EU.

1.

Markets and policy

1.1 Introduction

Biomass has been defined by the International Energy Agency as the 'sleeping giant' among the renewable energy sources. This definition refers to both the fundamental role played by biomass as the first renewable energy source at the global level, and to the potential role of bioenergy and its woody component in the total energy budget. Also, wood represents the first renewable within the European Union (EU). The Renewable Energy Directive of 2009 is driving the demand for biomass on a steep upward curve: a recent study projects an additional demand of up to 200 million m^3 within the next 10 years. This development is the result of market forces and policy decisions – two interconnected driving factors that will be considered in this chapter.

Some structural factors are enhancing the complexity of the analysis of the markets and policies related to wood energy:

- Self-consumption and micro and small enterprises operating on local-scale value chains continue to play a traditional two-fold role: on one hand it is perceived as a positive factor in policy analysis; on the other, it may create some problems in collecting data and monitoring market developments.
- Solid biomass demand is connected to many diversified and mutually competitive final uses, both internal to the energy sector (electricity vs. heating generation; large scale energy plants vs. family run boilers) and with alternative non-energy (i.e. industrial) uses such as cellulose-pulp and wood-panels. In relation to market analysis, this structural factor is giving stability to the demand; however, it is also stimulating innovations in raw material saving technology and in reducing the costs of logistics, as well documented from the expanding long-distance trade of wood biomass. With regard to policy-related aspects, competition in the use of solid biomass is creating coordination problems while implementing different sector policies; moreover, policy failures and conflicts are quite frequent, such as public investments in gas distribution in remote rural areas where public incentives for biomass heating equipment are made available.
- Biomass consumption is strictly associated with relevant externalities, both positive and negative, in relation to environmental and social impacts. Biomass consumption can support the maintenance of active management in otherwise abandoned forests that are exposed to high risks of fire and pest attacks; conversely, it can stimulate forest degradation and land conversion from natural and semi-natural systems to plantations. Likewise, environmental externalities are those connected to the impacts of bioenergy consumption on carbon sequestration in the growing stocks and the harvested wood products as well as on carbon fossil

fuel substitution. The use of wood for energy generation is characterized by relatively low added values and limited employment effects; however, local value chains based on bioenergy may create relevant positive externalities in the quality of life and income of rural populations. Again, market analysis and policies design have to face challenging problems at the international, regional and local levels when externalities are considered.

The ongoing discussion on a draft text for a European Union Directive on sustainability criteria for solid biomass, in addition to the Sustainability Criteria for Liquid Biofuels already in vigor (Articles 17(2) to 17(5) and Article 18(1) of the Renewable Energy Directive), is a clear example of the complexity of reaching a consensus on the definition of sustainable production, trade and consumption, when externalities have to be considered and a 'think globally, act locally' approach should be implemented.

While European wood production will be insufficient to satisfy the rising bioenergy demand, being limited by both high production costs and access to suitable lands, a number of critical environmental and socio-economic concerns will affect the governance of the sector by European institutions. A preliminary step in defining bioenergy procurement policies based on environmental integrity, economic efficiency and social equity criteria is to have a clear knowledge of consumption patterns, production levels, and the trade flows of biomass for energy. This market analysis will be presented in Chapter 1.2, with a prevalent focus on the fundamental topic of the dependence of the European market from foreign imports (Chapter 1.5). Based on the data of market conditions, the set of policies that are influencing bioenergy supply in Europe will be described (Chapter 1.3) in order to discuss the impacts of bioenergy policies on the forest sector markets in Europe (Chapter 1.4).

1.2

Consumption of renewable energy and wood fuels in the European Union

Esa Ylitalo and Mika Mustonen

Renewable energy and wood fuels

According to Eurostat, the share of renewable energy in the *Gross inland energy consumption* in the EU Member States was approximately 10%, or 7,077 petajoules, in 2011. Since 2000, this share has increased by 4 percentage points. The most important sources among renewable energy are wood fuels (wood and wood waste), which covered 48%, 3,378 petajoules, of the total consumption of all renewable energy in the EU in 2011 (Figure 1).

Since 2000, the consumption of wood fuels has increased more than 50%. Their share of all renewable energy has, however, simultaneously decreased by seven percentage points. This is due to the relatively higher rate of growth of other renewable energy sources (e.g. liquid biofuels, wind power, biogas and solar energy).

In 2011, the share of wood fuels of the national consumption of all renewable energy was the most significant in the Baltic and Nordic countries, and in Eastern Europe (Figure 2). In Estonia, 95% of all renewable energy consumed consisted of wood fuels. The share exceeded 80% in Lithuania, Finland and Poland. Germany, which accounts for approximately one-seventh of the total EU, is the largest single consumer.

Wood-based primary energy production by sub-groups

Eurostat's energy statistics concerning gross inland consumption do not provide information on the division of wood fuels into sub-categories. As the sub-division here is derived from the statistics on primary energy production, the figures presented are not fully comparable with the data on gross inland energy consumption given above and should be considered as an estimate. However, they indicate the importance of each sub-category in each country and the differences between the countries. Evidently, some countries have not been able to extract figures for all sub-categories of wood fuels. For example, Germany has reported all wood-based primary energy production in the sub-category other wood and wood waste, which overemphasizes the share of this sub-category in the presented figures.

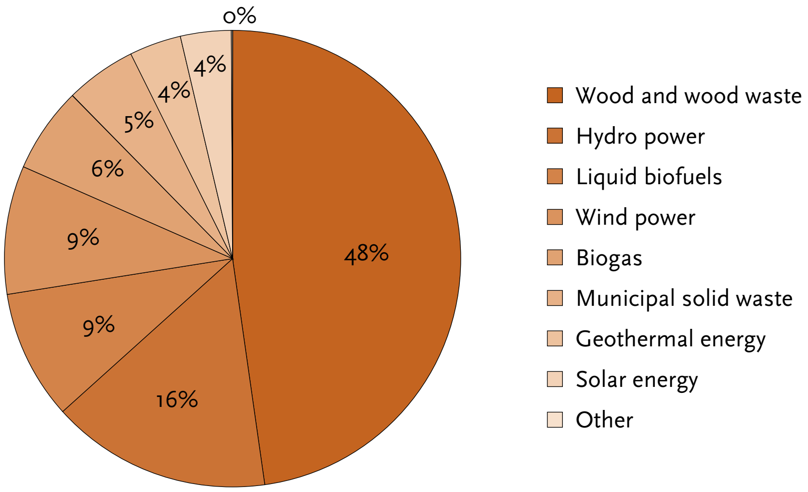

Figure 1. Share of renewable energy sources in gross inland consumption of renewable energy in the European Union (2011). Data source: Eurostat.

Box 1. Energy statistics and monitoring renewable energy consumption in Europe

The Statistical Office of the European Communities – Eurostat – is responsible for the compilation of statistics on energy consumption at a European level by country. The basic data are collected by the national statistical institute (or other designated authorities) in each country and delivered to Eurostat. The energy statistics are based on harmonized methodology and classifications, which allow a high level of comparisons among countries. In addition to the current 28 Member States, statistics are also produced for EU candidate countries as well as EFTA countries.

The promotion of renewable energy is among the key elements in the EU's energy policy. Directive 2009/28/EC on the promotion of the use of energy from renewable sources established accounting criteria for mandatory targets concerning the year 2020 for each Member State. These mandatory national targets are consistent with a target of at least a 20% share of energy from renewable sources in the Community's gross final consumption of energy in 2020. Energy statistics produced by Eurostat are a key element in monitoring how the targets are met.

Each year, the International Energy Agency (IEA), Eurostat and the United Nations Economic Commission for Europe (UNECE) collect annual energy statistics using a set of five joint questionnaires (oil, coal, gas, electricity and renewables) based on harmonized definitions, units and methodology.

The UNECE/FAO Forestry and Timber Section also produces statistics on sources and uses of wood energy based on its biennial joint questionnaire directed to UNECE member countries (Joint Wood Energy Enquiry – JWEE). The sources in the JWEE include basic fragments like the woody biomass from forests, forest industry by-products and wood waste (incl. recycled wood). End uses are reported separately, divided among wood use for power and heat generation, for industries' own use (mainly forest-based industries), and wood used by households. The JWEE presents figures basically for UNECE member countries; in 2011, the coverage of the results was 28 out of 53 countries. In this chapter, the Eurostat statistics for EU Member States are used.

The data on wood used for energy purposes are inconsistent in several European countries. There is, for example, evidence that data collected on fuelwood consumption is in many countries underestimated due to its informal use by mainly rural households. Another reason is that traditional statistics on the production and trade of roundwood does not consider to its end use (forest industry vs. energy generation). Data quality for other renewable sources than wood (hydroelectricity, solar power, etc.) can be found more consistent.

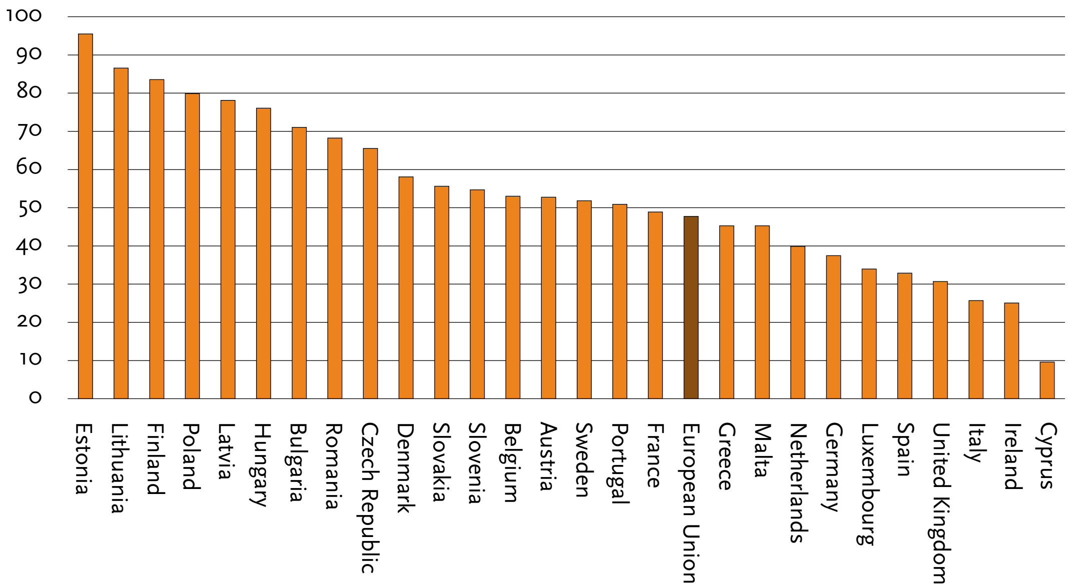

Figure 2. Share of wood and wood waste in gross inland consumption of renewable energy in the European Union by Member State (2011). Data source: Eurostat.

Wood fuels used for primary energy production in the European Union by sub-category (2011). Data source: Eurostat.

Wood (fuelwood from forests)	49%
Wood waste (solid by-products from forest industries)	17%
Black liquor	15%
Other wood and wood waste (e.g. recycled wood)	20%
Wood fuels, total	100%

The primary energy produced by wood fuels (excluding vegetal material) in the EU amounted to 3,076 petajoules in 2011. The largest wood-based primary production figures were recorded for Germany, France, Sweden and Finland.

In Italy and Malta, wood covered all wood-based primary energy production while in Slovenia, Romania and Greece the share was over 90%. In France, wood reached the highest single production figure; however, it is obvious that the figure reported for France also includes other categories such as wood wastes. Wood waste plays an important role in Ireland and Lithuania, comprising approximately 60% of the wood-based primary energy production. The largest single production figures of wood waste were recorded for Sweden, Austria and Finland, resulting from the central role of the wood-products industries in these countries.

Black liquor produced by the pulp industries had the largest share in Portugal, Slovakia, Sweden and Finland, accounting for almost half of wood-based energy production.

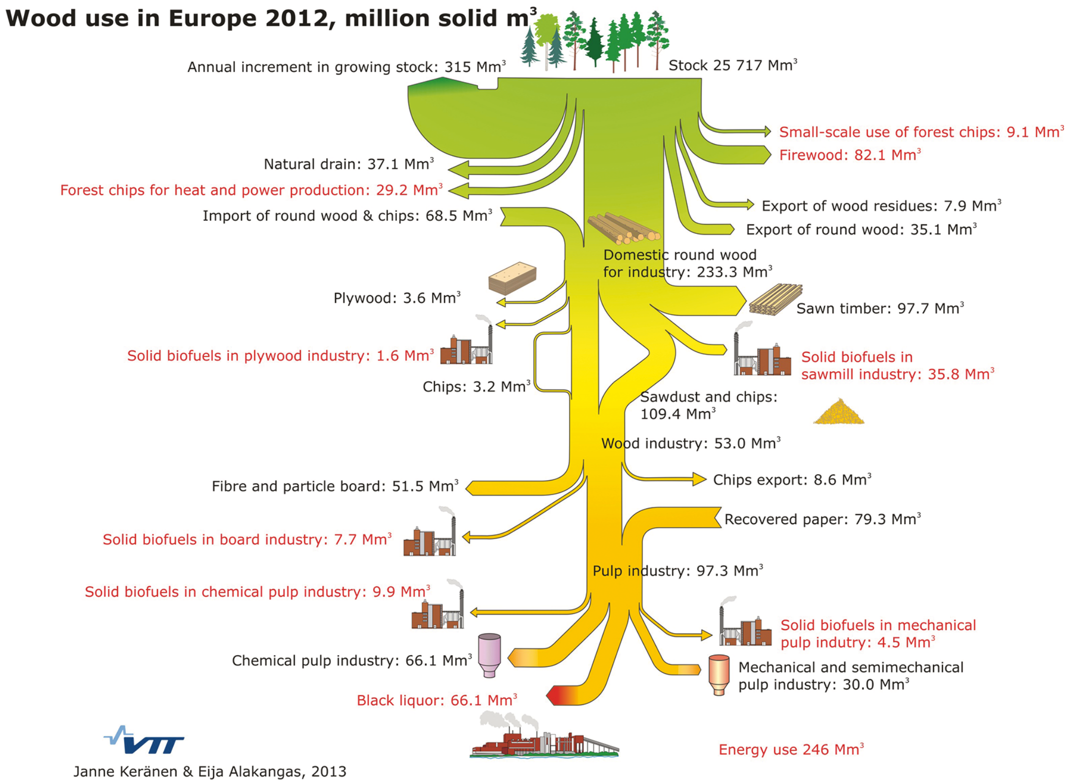

Figure 3. Wood use in Europe, 2012. Source: AEBIOM Bioenergy Outlook 2013.

The single production figures of black liquor were by far the largest in Sweden and Finland. The sub-category other wood and wood waste was most significant in the Netherlands and Poland accounting for 30% of the total (excl. Germany which reported all wood-based energy in this sub-category).

It is worth noting that the use of wood fuels for energy is strongly connected with the industrial use of roundwood. This is also shown in the statistics of wood use, which primarily measures cubic meters of wood used for different purposes, and is hence not harmonized and fully comparable with energy statistics measured in energy units (Figure 3). Almost half of the wood used in the forest industries in Europe ends up to energy use in the form of bark, sawdust and wood particles, as well as black liquor from pulp-mills. The use of European forests as well as EU imports of wood for sawn goods, wood-based panels and pulp plays an important role the in supply of wood fuels in the form of forest industry by-products. The same refers to the supply of forest chips converted from logging residues and stumps from removals of industrial roundwood. Moreover, forest industry products are also used for energy generation at the end of their life cycle.

According to the results of Joint Wood Energy Enquiry 2011 (for Europe, excluding the Russian Federation), most of the wood fuels (41%) were consumed by households. Consumption by industries (mainly forest-based) accounted for 29% of the total and for power and heat production 28%.

Table 1. Share of renewable energy in gross final consumption of energy in the European Union by Member State (2005–2011). Data source: Eurostat.

Area/ Member State	2005	2006	2007	2008	2009	2010	2011	Target 2020	Need to be increased 2020/2011, percentage points
EU27	8.5	9.0	9.7	10.4	11.6	12.5	13.0	20	7.0
Austria	23.8	25.3	27.2	28.3	30.2	30.6	30.9	34	3.1
Belgium	2.3	2.6	2.9	3.2	4.4	4.9	4.1	13	8.9
Bulgaria	9.2	9.4	9.0	9.5	11.7	13.7	13.8	16	2.2
Cyprus	2.6	2.8	3.5	4.5	5.0	5.4	5.4	13	7.6
Czech Republic	6.1	6.5	7.4	7.6	8.5	9.2	9.4	13	3.6
Denmark	16.0	16.4	17.8	18.6	20.0	22.0	23.1	30	6.9
Estonia	17.5	16.1	17.1	18.9	23.0	24.6	25.9	25	-0.9
Finland	28.6	29.8	29.4	30.7	30.4	31.4	31.8	38	6.2
France	9.5	9.6	10.2	11.3	12.3	12.8	11.5	23	11.5
Germany	6.0	7.0	8.3	8.4	9.2	10.7	12.3	18	5.7
Greece	7.2	7.4	8.4	8.3	8.5	9.8	11.6	18	6.4
Hungary	4.5	5.0	5.9	6.5	8.0	8.6	9.1	13	3.9
Ireland	2.8	3.1	3.6	4.0	5.2	5.6	6.7	16	9.3
Italy	5.1	5.5	5.5	6.9	8.6	9.8	11.5	17	5.5
Latvia	32.3	31.1	29.6	29.8	34.3	32.5	33.1	40	6.9
Lithuania	17.0	17.0	16.7	18.0	20.0	19.8	20.3	23	2.7
Luxembourg	1.4	1.5	1.7	1.8	1.9	2.9	2.9	11	8.1
Malta	0.0	0.0	0.0	0.0	0.0	0.2	0.4	10	9.6
Netherlands	2.1	2.3	3.0	3.2	4.0	3.7	4.3	14	9.7
Poland	7.0	7.0	7.0	7.9	8.8	9.3	10.4	15	4.6
Portugal	19.8	20.9	22.0	23.0	24.6	24.4	24.9	31	6.1
Romania	17.6	17.1	18.4	20.3	22.3	23.4	21.4	24	2.6
Slovakia	6.6	6.9	8.2	8.1	9.7	9.4	9.7	14	4.3
Slovenia	16.0	15.6	15.6	15.0	19.0	19.6	18.8	25	6.2
Spain	8.4	9.1	9.7	10.8	13.0	13.8	15.1	20	4.9
Sweden	40.4	42.4	43.9	45.0	47.7	47.9	46.8	49	2.2
United Kingdom	1.4	1.6	1.8	2.4	3.0	3.3	3.8	15	11.2

Renewable energy sources in gross final consumption of energy

Directive 2009/28/EC defines the accounting criteria and 2020 targets for the share of energy from renewable sources in terms of *gross final consumption of energy* for each Member State. The states are, however, independently allowed to define the renewable sources consumed and the promotion measures used to achieve the targets. The starting point and target figures vary significantly by country (Table 1). Those that have the furthest to go before they reach their 2020 renewable-energy target – i.e., the need to increase the share by approximately 10 percentage points or more – are the countries situated in the western part of Europe such as France, the United Kingdom and the Netherlands. Estonia has already achieved and exceeded the defined target with Sweden and Bulgaria close to reaching the target. For Sweden, where around one third of renewables consists of hydro power, the set target is the highest: almost half of its gross final energy consumption should be covered by renewable energy. For Latvia, this share is 40% and for Finland 38%.

Imports of renewable energy may play an important role in reaching the targets. According to Eurostat, the EU's total imports of biomass-based renewable energies was 478 petajoules (7% of the total renewable energy consumption) in 2011, of which 20% to Italy, 15% to the UK and 12% to Spain.

Definitions

Gross inland energy consumption = Total quantity of energy resources used for all purposes (Primary energy production + Import – Export +- Stock Changes).

Gross final consumption of energy = The energy commodities delivered for energy purposes to industry, transport, households, services (including public services), agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production as well as losses of electricity and heat in distribution and transmission.

Recommended reading

European Bioenergy Outlook 2013 – statistical report. AEBIOM, 120 p

Šturc, M. 2012. Renewable energy. Analysis of the latest data on energy from renewable resource. Statistics in focus 44/2012. Environment and Energy. Eurostat. 7 p.

1.3

Forest-related policies affecting bioenergy markets in Europe[1]

Mauro Masiero, Bart Muys and Birger Solberg

Introduction

The increasing interest in the use of forest biomass as a renewable energy source has activated policy developments at all geographical levels from international and national to local. Given their high relevance for the actors in the sector, we focus in this chapter on presenting an overview of policies at the EU level that are relevant for the development of sustainable biomass energy from forests.

EU forest policy

Articles 2 and 6 of the Amsterdam Treaty (1997) defines that the EU has responsibility over any impacts produced by economic development on environmental resources, including forests. Given all these intermediate steps, it was only in 1998 that the EU adopted a Forestry Strategy representing the first significant attempt to create an EU-wide framework for forestry. A mid-term evaluation of the Strategy in 2005, however, revealed the need for strengthening coherence between different EU policies and for improving coordination between the European Commission and the Member States. In this perspective, the EU Forest Action Plan for the period 2007–2011 was adopted in 2006. While trying to define practical aspects of policy action, through four main objectives and 18 key-actions (including the promotion of the use of forest biomass for energy generation), the Plan remains rather general and can have only indirect effects in terms of improving coordination among national policies. In 2013, a new version of the EU Forest Strategy was issued. The document acknowledges the role of energy biomass and stresses the importance of wood mobilisation. It encourages Member States to exploit forest resources in a way that minimises the impact on the environment and climate, and prioritises the forest outputs that have higher added-value, create more jobs and contribute to a better carbon balance. The focus, therefore, is on a cascade approach and active forest management.

In 2011, the EU Member States also entered a Pan-European process for the negotiation of a Legally Binding Agreement (LBA) on Forests in Europe. Accordingly, an Intergovernmental Negotiating Committee (INC) was established with the mandate to develop such an agreement that aims to promote the sustainable management of forests in Europe. Once approved, the LBA will represent an absolute premiere worldwide.

1 Francesca Ferranti is acknowledged as the author of Box 2.

Box 2. Main EU policies affecting the production and use of energy wood

Some of the most important EU policies affecting the energy wood context are listed and described here, also the policies' effects on the production and use of forest wood as an energy source are explained.

Policy	Description	Effects
Common Agricultural Policy and Rural Development Policy	They aim at the competitiveness of the primary sector and at promoting rural development, amongst other things by offering financing opportunities to farmers and forest owners.	Forestry measures and related activities aimed at producing forest energy wood can be directly financed. These policies determine the availability, types and costs of forest woody biomass to the energy sector.
Directive 2002/91/EC on energy performance of buildings	It promotes energy performance of new and existing buildings, for example by fostering the efficient use of installations like boilers and air-conditioners, and of renewable energies.	It stimulates demand for energy wood, since this is among the energy sources most broadly used for efficient heating technologies like the cogeneration of heat and electricity and district heating.
EU Emission Trading Scheme (Directive 2003/87/EC)	The core of EU climate change policy – it applies a market system to cost-effectively reduce greenhouse gas emissions. It applies a 'cap and trade' system: it imposes a limit to industries´ total emissions, and it allows trading the assigned 'emission allowances' which can be used to emit or can be sold on the market.	By putting a price on greenhouse gas emissions, it fosters the substitution of fossil fuels with less carbon-intensive energy sources, therefore strengthening the economic competitiveness of woody biomass and other renewable energy sources.
Renewable Energies Directive (Directive 2009/28/EC) and Biofuels Directive (Directive 2003/30/EC)	By establishing individual legally binding targets for the share of renewable energies consumed in the various EU Member States, they promote an increased use of renewable energy sources for all energy sectors and in particular for the transport sector.	They force EU Member States to increase the use of wood and other renewable energy sources to reach the mandatory targets.

The data were collected and analysed within the project COOL (COmpeting uses Of forest Land; www.cool-project.org). Author: Francesca Ferranti.

The EU forest policy sensu stricto has only limited impact on the development of bioenergy from the forest, as a consequence of the EU legislative framework that only provides a marginal role for the European Commission in policy design, financing and implementation.

Climate policy

The EU adopted climate change prevention as a strategic priority. In this perspective, investments in green technologies and good practices that cut emissions represent a priority that could also boost the economy, create jobs and strengthen Europe's competitiveness at the global level. For the first commitment period of the Kyoto Protocol (2008–2012), the 15 countries that were EU members before 2004 ('EU15') committed to reduce their collective emissions to 8% below the 1990 levels. According to EC strategies, 1% out of 8% of the EU15 target was supposed to be reached through forest activities.

The most relevant market tool for the reduction of greenhouse gas (GHG) emissions within the EU is the European Union's emissions trading scheme (EU ETS), adopted by Directive 87/2003 and operative since 2005. The scheme is organised as a cap-and-trade system and imposes an emission threshold (cap) to the most energy intensive economic segments. However, companies can reduce their emissions by energy savings or reducing their production levels, and by selling any (trade) emission credits they do not use to other companies. The EU ETS scheme does not allow investments in the primary sector to generate credits. Companies can, however, use biomass and other renewables to produce their own energy, thus reducing their GHG emissions and indirectly valorising agro-forestry activities at the EU level.

Climate policy is closely connected to energy policy, where the role of biomass is paramount. In its efforts to become a highly energy-efficient, low carbon economy, the EU adopted the Climate and Energy Package in 2009 – a set of binding legislation that aims to ensure the EU meets its ambitious climate and energy targets for 2020. These targets, known as the '20-20-20' targets, set three key objectives for 2020: (i) reduce EU greenhouse gas emissions by 20% from the 1990 levels; (ii) raise the share of EU energy consumption produced from renewable resources to 20%; and (iii) improve the EU's energy efficiency by 20%.

The link between climate and energy policies can also be found with regard to energy efficiency initiatives in the building sector. The adoption or enhancement of low and zero carbon technologies (LZCT), such as micro-CHP (combined heat and power) and biomass boilers, can be a valid solution.

Through incentives for the private sector and procurement policies for the public sector aiming at the adoption of low-carbon technologies, the EU's climate policy is strongly stimulating the demand for biomass.

Energy policy

Directive 2009/28/EC (EU-RED) requires that at least 20% of the EU's total energy consumption is generated from renewables by 2020; in this perspective, it confirms forest biomass as the most important renewable energy source in Europe in the EU's 20-20-20 strategy: wood and wood wastes represent 47% of gross consumption of renewable energy and 67% of bioenergy use. The EU-RED also includes a set of mandatory sustainability criteria, including monitoring and reporting requirements for liquid biofuels such as Fisher-Tropsch biodiesel from forest biomass. Biofuels are required to fulfil all sustainability criteria in order to count towards EU targets and to be eligible for financial support. For example, the EU-RED excludes several land categories with recognised high biodiversity values from being used for biofuel production: (a) primary forests and other wooded land; (b) areas designated for nature protection or for the protection of rare, threatened or endangered ecosystems or species; (c) highly biodiverse grass-lands, either natural or non-natural.

In 2013, a proposal for a Directive on 'sustainability criteria for solid and gaseous biomass used in electricity and/or heating and cooling (in district heating, for instance) and biomethane injected into the natural gas network' was published. One aspect that needs to be reinforced is the focus on the 'cascading approach' (see Chapter 5.3). This approach would help creating synergies between industry and the energy sector in accessing wood resources and, above all, would be in line with the EU Resource Efficiency Initiative, which emphasises resource use in the most efficient way.

The ambitious targets of the EU's energy policy imply the need of criteria to assure that bioenergy production and trade are sustainable, and not detrimental for society and the environment. New rules for forest biomass are underway that should be in line with the existing rules for liquid biofuels

Rural Development Policy and Common Agriculture Policy

With the CAP reform of 2005, forest measures became a fundamental part of the Rural Development Policy. As for the 2007–2013 period, nine forestry-specific and six forestry-related measures were defined within this policy. As a consequence, 1–1.5% of the CAP funding was originally intended for forestry measures, i.e. 7–9% of the EU Rural Development Policy funding (Agricultural Fund for Rural Development, EAFRD). Many of these measures were directly linked to wood mobilisation and, in many cases, the production of biomass for energy. As for wood mobilisation, measures include subsidies for thinning, pruning and other forest operations that improve the economic value of forests, as well for improving road networks and infrastructures (at least 16,000 km of forest roads are expected to be built) (Table 2).

In line with the Europe 2020 growth strategy and the overall CAP objectives, the European Commission proposal for rural development policy for the period 2014–2020 is organised according to six priorities. Among them, Priority 5 reads as '*Promoting resource efficiency and supporting the shift towards a low-carbon and climate-resilient economy in the agriculture, food and forestry sectors*'. One of the areas of intervention under Priority 5 is facilitating the supply and use of renewable sources of energy, by-products, wastes, residues and other non-food raw materials for the bio-economy. In addition to this, Member States may include within their rural development programmes thematic sub-programmes, contributing to the EU's priorities for rural development, aimed at addressing identified specific needs. These include short supply chains, which might represent an interesting future development opportunity for the woody biomass sector. The European Commission has defined a short supply chain as 'a supply chain involving a limited number of economic operators, committed to cooperation, local economic development, and close geographical and social relations between producers and consumers'.

When considering the new rural development policy, a strong focus on environmental services and greening is expected. For many years, following the 'Kielwasser theory' developed by Rupf (1960), forest management focused almost exclusively on wood production, considering all other functions as secondary values depending on the former. Today, forestry is expected to be more and more multifunctional, i.e. to support the provision of a wide range of products and services economically, and in socially and ecologically sustainable ways. There can be both positive interactions and trade-offs between wood mobilisation in general, and the provision of other ecosystem services such as recreation, biodiversity conservation, carbon sequestration and landscape amenities.

Table 2. Examples of rural development measures for biomass and wood mobilisation during the CAP 2007–2013 programming period. B = biomass specific; WM = wood mobilisation in general.

Measure			B	WM
No	Description	Examples and notes		
121	Modernisation of agricultural holding	Short rotation coppice for biomass production, mostly with reference to bioenergy production (minor part of total allocated amounts).	X	
122	Improving the economic value of forests	Pre-commercial thinning and replacement of low value forest stands.		X
123	Adding value to agricultural and forestry products	For micro-enterprises only: support for harvesting machinery, (portable) sawing mills, and other processing facilities (e.g. woodchip and pellet production).	X	X
124	Cooperation for development of new products processes and technologies in the agriculture and food sector and the forestry sector	Initiatives for the substitution of fossil fuels.	X	
125	Infrastructure related to the development and adaptation of agriculture and forestry	Building and/or improving forest roads.		X
221	First afforestation of agricultural land	Afforestation for productive or protective purposes.		X
223	First afforestation of non-agricultural land			X
225	Forest-environment payments	Ex-ante or ex-post forestry practices such as vegetation control, thinning, diversification of vegetation structure.		X
226	Restoring forestry production potential and introducing prevention actions			X
227	Non-productive investments	Thinning and pruning to improve the ecological value of forests.		X
311	Diversification into non-agricultural activities	Bioenergy production as one of the possible actions.	X	
312	Support for business creation and development	It may cover the processing of forest products, and bioenergy production and related actions.	X	
321	Basic services for the economy and rural population	Increase of the share of decentralised produced and used heat energy out of biomass.	X	

The EU CAP and Rural Development Policy offer a large variety of opportunities for countries and regions to stimulate wood mobilisation in their forests in an optimized balance with other development opportunities and ecosystem services, providing the most appropriate job, income and wellbeing opportunities for rural communities.

Trade policy

Achieving the renewable energy target by 2020 will encourage wood mobilisation from domestic forest resources and also increase imports from other regions. In the last few years, the traditional trade policy has been completed by new initiatives aiming to tackle illegal logging practices and, in particular, the international trade in illegally harvested wood. As a major wood importer, the EU has been a frontrunner in this arena and has adopted different specific initiatives. The Forest Law Enforcement Governance and

Trade (FLEGT) Action Plan – approved in 2003 and then implemented by two regulations in 2005 and 2008 – defines several measures, the most prominent being the negotiation of Voluntary Partnership Agreements (VPA) with wood producing countries that export their products to the EU. While only six countries have signed a VPA with the EC to date, a number of negotiation processes are currently taking place.

A second initiative launched by the EC is Regulation (EU) 995/2010, also known as the EU Timber Regulation (EUTR). EUTR, which came into force in March 2013, prohibits the placing of illegally harvested timber or products derived from such timber to the EU market, including firewood, pellets and wood chips. In this perspective, those who place timber on the market are called operators and shall exercise 'due diligence', i.e. a set of procedures for collecting information, performing risk assessment and mitigating illegality risks. While the FLEGT Action Plan only applies to imported wood, EUTR covers both imported and domestically sourced wood. The due diligence system might also imply increased supply costs for EU forest owners, with unequal effects in relation to the scale of their activity, affecting micro and small enterprises.

The new European trade regulations will help to avoid illegal trade flows of woody biomass for bioenergy, but may have side effects in terms of increased supply costs, in particular for small forest enterprises.

Conclusions

It has become clear that actors in forest biomass for bioenergy are influenced not only by forest policies, but also by extremely complex governance involving several other policies such as climate policy, energy policy, rural development policy, common agricultural policy, and trade policy. Each of these policy groups and sub-groups has different characteristics and peculiarities, and might influence the development of the bioenergy sector both within and outside European borders.

New scenarios emerging from the expansion of the biomass sector will require due considerations of the impacts and future challenges they may impose on present and future EU policies.

Recommended reading

European Network for Rural Development (2011). A short guide to the European Commission's proposals for EU rural development after 2013. http://enrd.ec.europa.eu/app_templates/filedownload.cfm?id=6C815B37-9A49-EB8F-3259-3A4164913EB1 [Accessed 24th September 2013]

EU timber Regulation Portal. http://ec.europa.eu/environment/eutr2013/

FLEGT Voluntary Partnership Agreements. Ensuring legal timber trade and strengthening forest governance. http://www.euflegt.efi.int/portal/

Fondse, M., Wubben, E., Korstee, H. and Pascucci S. 2012. The economic organizations of short supply chains. 126th EAAE Seminar "New challenges for the EU agricultural sector and rural areas. Which role for public policy?" Capri 27-29 June, 2012.

Rupf, H. 1960. Wald und Mensch im Geschehen der Gegenwart. Allgemeine Forstzeitschrift 38:545-5552

1.4

Impacts of forest bioenergy and policies on the forest sector markets in Europe: What do we know?

Birger Solberg, Lauri Hetemäki, A. Maarit I. Kallio, Alexander Moiseyev and Hanne K. Sjølie

Introduction

The main political objectives of the EU's renewable strategy are decreased use of fossil energy, reduced CO_2 emissions and increased energy self-sufficiency. Wood-based bioenergy plays a central role in this strategy, and the potential increase in wood demand for bioenergy production is also of high interest for the EU's forestry and forest industries.

First, forest bioenergy production opens possibilities for new investments, production and employment in forest biorefineries and energy companies producing heat and power. Since much of these investments are expected to be located in rural areas that have low business opportunities, it would serve to enhance the economic viability of these areas.

Moreover, bioenergy production generates new demand for wood, and therefore benefits the forest owners through higher wood prices. On the other hand, this can weaken the profitability of the existing forest industries, as it may lead to increased production costs of the wood-using industries. If this change is caused by policies rather than markets, it may cause unwanted indirect effects like inefficiencies and distorted markets. Changes in wood demand can also have significant implications to the international trade in biomass. Some countries, such as Germany and the UK, have ambitious, renewable energy targets; and if they implement policies that give strong support for using forest biomass for energy, their forest biomass imports may increase from the Nordic and Baltic countries, Canada and Russia, among others.

Given the above, it is important to assess the future course of development of wood use for energy and the potential impacts of this development on the EU forest sector. These developments may vary significantly according to particular circumstances such as specific country conditions, technologies used for production, and the implementation of the renewable energy sources (RES) and climate policies.

Furthermore, the impacts of the RES policy may vary considerably between different the players such as heat and power producers, forest industries, biorefineries and forest owners.

In recent years, several studies from different disciplines have been published on various aspects within this rather large and complex issue. Since the users of the research results – policy makers and forest and energy sector stakeholders – may have difficulties in comprehending the overall implications of what science has published, there seems to be a need for a policy relevant synthesis of the existing studies. What, in essence, are the policy relevant messages that arise from recent studies and what primary issues require more science-based data? The current chapter seeks to address these questions.

We will focus on the literature that analyses the RES implications to the forest industry and forest biomass markets, and mainly on economic analyses of these implications. The chapter summarizes major results from some recent studies, discusses their main policy implications, and identifies issues where further research is needed. Although the studies reviewed are based on economic analysis (except one looking also on more general aspects), they apply different methodologies, have different regional scopes and background assumptions, and use different terminologies. While this might complicate direct comparisons of the results, some general results and insights have emerged and are presented.[1]

Increased use of energy wood is not a threat to the EU's forest industry

The reviewed studies indicate that the contribution of EU-based wood energy is likely to be modest in achieving the EU target for increasing the share of renewable energy to 20% of the energy consumption by 2020, even at high carbon price levels. It also appears that the forest industry will continue to keep its important role as a producer and user of wood-based energy. This will take place despite the possible decline in consumption and production of some end products (such as graphic papers) that is likely to decrease the production of pulp, which is also an important generator of bioenergy.

Nevertheless, a large share of the woody biomass going to energy production will also consist of the by-products of the forest industry in the future, including bark, sawdust and black liquor, as well as the supply of logging residues and stumps that are strongly connected to industrial wood harvests.

Moreover, the studies suggest that if the carbon price is a sole instrument spurring the use of woody biomass for energy, it needs to rise to quite a high level before the competition between forest industries and the energy sector over the forest biomass starts to affect production in the forest industry.

1 The present chapter is based on the study by Solberg et al. (2014), which provides a more detailed analysis and references of the reviewed studies (see Recommended Reading).

The widely cited EUwood study's medium scenario suggests that the EU forest biomass supply (from forests and cascading use) would increase by 11% from 2010 to 2030 (Mantau et al., 2010). However, assuming the EU 20-20-20 target and the continuation of forest industry production in the EU following the trend over the past decades, the study estimates that the demand for forest biomass would increase by 73%. As a result, there would be a shortage or gap of 316 million cubic meters in 2030, which would amount to 22% of the total EU forest biomass demand.

The above gap has aroused concerns that a scarcity of wood could lead to fierce competition over woody biomass between the buyers and to a significant loss of forest biodiversity due to the increasing use of forest biomass. However, studies based on economic theory and market models project the demand for wood biomass to be significantly lower in the EU, even at rather moderate wood price levels. In fact, there are three main factors not included in the EUwood study analysis which, in our opinion, imply that the study is most likely significantly overestimating the future demand for forest biomass harvested in the EU (some of these factors are also included in the economic studies we have reviewed):

1. The structural changes in global and EU forest products markets are likely to result in a lower demand and production of forest products in the EU than what could be anticipated by simply extrapolating the past trend, as the EUwood study does. Accordingly, the forest biomass demand for industrial purposes is also likely to be lower.
2. The EUwood study does not take into consideration the impacts of international trade in forest biomass. The EU already imports considerable quantities of forest biomass, both for the forest industry and bioenergy purposes. These imports are likely to increase in the future, given that the markets and policies in the EU provide needs and incentives for this.
3. Forest biomass markets, bioenergy production and traditional forest industry production react to market incentives, such as the prices of raw material and end products. These market adjustments may be significant and also reduce the 'gaps' between supply and demand for forest biomass. For example, the potential increases in forest biomass prices decrease its demand.

There is a clear need to make an assessment of the future EU forest biomass demand, which also takes into account these three factors.

Uncertainty over future policies makes the business environment challenging for investors

The projected future energy wood demand varies significantly between the various studies. This indicates the high uncertainty that prevails over the future development of the use of energy wood.

Perhaps the most important source of uncertainty is political.

How will the carbon price develop in the future due to local or global climate policies, and what type of taxes and subsidies will be implemented for wood bioenergy and alternative competing energy forms? Will future policy treat woody biomass used for energy production as carbon neutral or not? Do the possible sustainable biomass criteria effect woody biomass utilization for energy? Clearly, while the answers to these questions are important for future development, there is high uncertainty regarding which policies should be implemented and what their more detailed content will be.

For example, the reviewed studies show that it is not only the level of carbon price (or other related policies) that has a large impact on the future use of wood for bioenergy it is also the carbon price development over time imposed by climate policies. Due to the high investment costs required for new heat and power and biorefining capacity, expectations on the directions of future climate and RES policies are decisive for investments in such technologies. Early signals for high future carbon prices will lead to higher investments. Given this uncertainty of the future carbon prices, additional RES policies could help promote new investments; however, they could also cause new unwanted problems as discussed below.

Sectoral policies may not be a cost-efficient way to achieve RES and climate policy targets

The choice of policy instruments to promote bioenergy strongly influences the use of wood biomass across the energy and forest industry sectors. Subsidies directed to one sector may harm the other sectors and can also increase the costs of mitigating climate change. For example, it has been found that subsides given for biodiesel production tend to increase the forest biomass price which, in turn, may decrease the production of wood-based heat and power in the region. In some cases, they could also decrease pulp production. Subsidising the co-firing of wood with coal in heat and power production can lead to lower displacement of coal in the whole energy system, and can also lead to higher displacement of gas, which emits less CO_2 than coal. While coal with wood co-firing may be a 'low-cost' option in the short term, it may cause major sustainability impacts in the long term because of forest degradation and increasing wood prices. A policy implemented to reach a desirable target can thus result in a situation whereby this target is even more difficult to reach. Moreover, even relatively modest subsidies for the production of energy from wood may result in a significant increase in the use of industrial wood for energy, and also lead to increased imports from outside the EU causing carbon leakage and concerns regarding the sustainability of these supplies. Consequently, such subsidies may not be cost-efficient from the point of view of reducing climate gas emissions.

Different RES polices used for the same purpose can also have different impacts, and may cause trade-offs with other policy targets. For example, a RES policy that is optimal on the basis of minimizing the costs of the policy to tax payers may be the worst policy if the objective is to minimize the side impacts to the forest industry.

> Subsidies may also have many other indirect distorting impacts, such as causing inefficient bioenergy productions.

For instance, it is possible that investment subsidies to new biorefineries result in too small production units, thus causing reduced scale efficiencies and suboptimal plant sizes. In summary, it is vital that the policy makers are aware of the many impacts of the policies, and that they have clear priorities guiding them to accept trade-offs between sometimes conflicting policy goals.

The need for a synthesis study taking into account environmental sustainability

Although not focused upon in this chapter, the issue of environmental sustainability is likely to bring additional challenges to policy makers. For instance, if the RES target is triggering woody biomass imports for bioenergy purposes to the EU, it is clear that these imports should meet the same sustainability standards as the EU has in place for forest biomass.

Although the EU has recently implemented means to inspect the legality of wood placed on the EU market, it does not guarantee all dimensions of sustainability of the imported wood. Another important sustainability issue is related to the carbon (and climate) neutrality of forest biomass as fuel.

It is currently a hot topic both in the policy and science arenas. It is also a very complicated issue where it is not easy to find simple solutions and widely applicable generalizations. Forest biomass production can be based on many different raw material sources and different technologies to produce bioenergy as well as various end products made from it such as heat, power, transportation fuels, or a combination of these. Also, the reactions of forest owners to RES policies may change their forest management practices which, in turn, may have significant carbon sequestration implications. As a result, the energy efficiencies and climate (carbon) impacts of RES policies and wood-based bioenergy productions may vary greatly. Clearly, there is a great need for further studies that synthesise the best scientific knowledge available on the carbon neutrality issue, and which highlight the importance and implications to policy making by considering consistently the interlinkage between bioenergy and climate policies.

Further research necessary, yet action needed beforehand

In summary, the policy makers are in a very difficult position. The operating environment for RES and climate polices is complex, and there are still many uncertainties related to the scientific information that could support such polices, as this review has demonstrated. '*One size fits all*', hardly exists for climate and renewable energy policies.

The studies reviewed here indicate that it is unlikely to be simple policy or technology solutions that are suitable for a wide range of situations or problems related to RES targets or mitigating climate change.

There is also a need to update the assessment and outlook of EU forest biomass markets by taking into account the factors outlined above. This is important not only for getting a better picture of the supply and demand balance in the EU forest biomass markets, but also for analysing many of the indirect impacts that the above mentioned factors may cause. This research should preferably include even more detailed forest sector modelling than applied in the previous studies, incorporating forestry dynamics, the complete current forest industry structure, potential new forest industry products, different types of technologies for producing wood-based bioenergy (including pellets, torrefied wood, liquid and gaseous biofuels), international trade, and various types of policy instruments. These studies should be complemented with foresight analyses that address the possible structural changes and new products that may be difficult to model, and for which we do not yet have data.

Nevertheless, it is likely that the policy makers do not have time to wait until more solid scientific evidence becomes available, as they need to act now even with incomplete information in order to try to mitigate the ever more evident climate change trends and their potentially drastic impacts. In such a case, and based on the already available studies, it would be advisable to consider the possibility that the woody biomass contribution for the EU RES target from wood harvested in the EU in the next decades may very well be significantly lower than has generally been thought.

Most likely, there will not be a 'gap' in the EU woody biomass demand and supply. However, policies aiming at increasing woody biomass utilization for energy in the EU should be implemented only after a thorough analysis of their long-term forest sustainability impacts.

Recommended reading

Koelemeijer, R., Ros, J., Notenbom, J., Boot, P., Groenenberg, H. and Winkel, T. 2013: EU policy options. PBL Netherlands Evironmental Assessment Agency, The Hague. Publication no. 1082. 46 p.

Mantau, U., Saal, U., Prins, K., Steierer, F., Lindner, M., Verkerk, H., Eggers, J., Leek, N., Oldenburg, J., Asikainen, A. and Anttila, P. 2010. EUwood – Real potential for changes in growth and use of EU forests. Final report. Hamburg/Germany, June 2010. 160 p.

Solberg, B., Hetemäki, L., Kallio, A.M.I., Moiseyev, A. and Sjølie, H.K. 2014. Impacts of forest bioenergy and policies on the forest sector markets in Europe – what do we know? EFI Technical Report 89. European Forest Institute.

1.5

European reliance on the world bioenergy market

Promode Kant, Anatoly Shvidenko, Warwick Manfrinato, Luiz Fernando de Moura and Petro Lakyda

The increasing gap between the biomass resource availability and demand in the EU is expected to be made up by imports from countries in eastern Eurasia, Africa and the Americas, which have been the sources of wood for energy in Europe. This huge increase in demand in Europe comes at a time when there is a similar trend across the globe with a worldwide emphasis on renewable energy. The European market, therefore, will face stiffer competition with the increasing domestic demands within the exporting countries as well as from countries like India and China that are strong on promoting renewable energy and have become major importers of wood. This would greatly influence the price dynamics of wood across the globe leading to a host of significant impacts that include enhanced incomes and more jobs for the rural poor, increased climate change mitigation benefits, and improved protection against desertification and soil and moisture losses with more lands under tree cover. However, these positives may also be accompanied with increased competition with food crops for land and water, a sharp rise in wood energy prices for the local poor, and the possibility of displacement of people from marginal lands under their possession in developing countries with poor governance. There are also serious environmental concerns of threats to biodiversity, damage to the existing vegetation, increased reliance on non-native species of higher productivity, loss of soil nutrients, and even doubts about the true extent of greenhouse gas emission reductions over the complete life cycle.

Russia, with almost a quarter of the global forest area, one fifth of the global forest growing stock and close physical proximity to the EU is the biggest potential source for bioenergy.

The Russian Energy Agency (REA) has estimated that Russian forest resources could be used for sustainably producing 1.2 billion tonnes of pellets, 315 million tonnes of ethanol and large quantities of syngas annually, in addition to the sustainable production of timber and non-wood forest produce. However, realizing this potential is unlikely in the 'business-as-usual' scenario as the lack of adequate road infrastructure limits industrial harvesting to just about 40% of its forest resources. A combination of organizational, financial and logistical causes further restricts the utilization of this resource. During the last decade, the actual average annual harvest was only around 170 million m^3 out of the estimated average annual allowable cut of 550 million m^3, roughly a quarter of which was used for energy.

Wood waste, the most preferred source of bioenergy generated at different stages of harvest and processing, totals up to 30–50% of the initial volume of logged growing stock. However, its use for energy production in Russia is low as more than three-quarters of logging enterprises in the country are too small to be able to invest adequately in the collection of logging residues and their transportation to neighbouring bioenergy plants. The utilization of lignocellulosic waste liquor in Russian cellulose and paper plants is similarly very low, covering barely 20–30% of their own energy needs in sharp contrast to most north European units which are energy surplus.

Pellet production capacity in Russia is two million tonnes per year; however, actual production is less than half of this figure. There are some 100 plants in operation – the largest has an annual capacity of one million tonnes and a number of new plants are in the offing. There is good potential for an immediate increase in the production of pellets by two to three times, both on account of industrial capacity and raw material availability. Production of biomass-based liquid biofuel is very limited with only one plant in the Kirov region producing bioethanol from wood waste as motor fuel. However, a few relatively large-scale projects on bioethanol production are in the process of being set up in the Omsk, Irkutsk and Kostroma regions in the Asian part of Russia.

The domestic market in Russia consumes about 60% of the national forest sector's production with the remaining mostly exported to Europe and China. During 2009, a total of 0.6 million tonnes of wood pellets was imported in the EU from Russia, 40% of which came from just two plants in the European North-West of Russia. In recent years, Russian exports to the EU have decreased substantially, partly due to a sharply enhanced export tariff for roundwood in order to stimulate the domestic wood industry, and also due to vastly increased demands from neighbouring China, which does not require timber certification.

Technologically, it is possible to blend syngas from wood in Eurasia with natural gas and supply it to consumers in the EU through the existing gas pipeline network.

The EU is a major consumer of natural gas from Siberia that is channelled through a network of pipelines. It is technically feasible to blend natural gas with syngas from wood; and given the vastness of wood resources in Siberia and European Russia, large-scale production of syngas could be made both economically competitive and compatible with the transport of natural gas for supply through the same pipelines. While Russia is also one of the few countries that have considerable experience of forest-based biomass gasification, the facilities are still on a small scale as easy access to natural gas has dampened the earlier enthusiasm for this resource. Only two small projects of 200kW each have been established during the last 10 years as components of larger agricultural enterprises; however, a few new projects of somewhat larger capacities (0.5–1.2 MW) are under construction in the Belgorod region of European Russia. Scaling up production significantly would require large investments in production facilities and the construction of forest roads as well as an extensive reorganization of forest management.

Since the forestry sector is not a priority of national economic policy making in Russia, it does not attract enough attention at higher political levels. Token supplies to the EU to earn some additional revenues are unlikely to get the necessary political support, which would be easier to obtain if the motivations are domestic. One possible way in which such support could be bolstered is through producing syngas in those remote parts of Russia that are not able to access natural gas and where the delivery of liquid fuel is very expensive. This could generate interest in the use of woody biomass for the production of electricity and heat, particularly in Russian Far East, with surplus available for export to the EU.

There is a risk, however, that Russian state gas and oil monopolies might not be interested in such developments. For Europe to be able to meet a large part of its future demand for bioenergy from Russian resources, proactive steps to initiate serious negotiations at the government and industry levels would be needed in order to lay down long-term stable policies on both sides that would benefit all stakeholders economically and ensure that the environmental integrity of these benefits is not called into question. Addressing this issue would require deft political handling built around collaborative measures that are politically attractive for Russia and bring them early economic benefits. Since this would mean a considerable reduction of greenhouse gas emissions, it could also be part of a larger strategic climate change dialogue between the EU and Russia.

Ukrainian forests need investments in management quality and transport infrastructure before they can become a large reliable source of bioenergy.

Past management practices have left the age structure of Ukrainian forests predominantly younger with less than 1% of its growing stock, the lowest in Europe, available for harvesting annually. In recent years, annual logging in Ukrainian forests has ranged from 13–16 million m^3 of timber. The potential availability of forest biomass in Ukraine is unevenly distributed across the country with the highest density in the Carpathian forests, followed by polissya, forest-steppe and the steppe. A large part of Carpathian forest resources is, however, technically inaccessible due to the lack of forest roads. While the state of the transport network is somewhat better in other regions, there are technical limitations such as the lack of industrial facilities for the effective utilization of the forests' energy potential. In general, taking into account the current age distribution of the forests in Ukraine, a significant increase of the proportion of mature stands can be expected over the next 10 years, leading to an increase in the amounts of forest biomass available for energy use.

Belarus is rich in forests that are reasonably well managed; however, almost a quarter of its forests are affected by Chernobyl radiation in varying degrees of severity and no harvesting is permitted over 0.5 million ha.

Almost a fifth of forests of Belarus are in wetlands or drained peatlands where extraction is difficult and costly. Younger, immature forests predominate due to past management practices. The mean annual increment of Belarus forests is 28.6 million m^3. The total

Figure 4. Major Russian gas pipelines to the EU (Reproduced with permission from Russian Analytical Digest, No. 113, May 15, 2012, ISSN 1863-0421, map originally created by Samuel Bailey, modified by the Research Centre for East European Studies, University of Bremen, Germany, after sourcing from Wikimedia Commons).

energy wood potential is 10.3 million m³, of which 7.8 million m³ is from stem wood; 0.5 million m³ from harvest residues; and 2 million m³ from energy wood plantations. The actual harvest of energy wood was 4.2 million m³ in 2007 and rose to 6.9 million m³ in 2011. The total production capacity of wood chips for energy is 4 million m³, but actual production in 2008 was less than one third. Similarly, of the total installed annual pellet production capacity of 133,000 tonnes, less than half was actually produced in 2008. With careful monitoring for radiation exposure, Belarus is potentially a good source for bioenergy imports to the EU.

Pellet supplies from North America are environmentally compatible with EU sustainability requirements, but would likely diminish over the coming decades as domestic needs grow.

The high calorific contents of wood pellets make them a preferred input for electricity generation – a good part of which is sourced from Canada and the USA. In the past, most North American wood pellet plants were small and used available residues from sawmills and from secondary processing facilities such as furniture makers. In the last few years, however, a number of new, large-sized mills have been built that process chipped roundwood in addition to the residues. The wood pellet industry is in its relative infancy in North America, and its recent growth has been fuelled by policies aimed at mitigating climate change and increasing opportunities for export to Europe. Southeast America has become a key wood energy exporter to Europe, providing tough competition to Canada, which has also been developing its wood fuel sector in British Columbia and in eastern Canada – both important strategic points in pellet production. Within Canada, the proportion of exports of wood pellets from British Columbia shows a decreasing trend while that from the east coast is rising, primarily because of relatively cheap transatlantic freight. Because of fast growing conditions, huge forest resources and lower freight, southeast United States is also a very attractive region for sourcing woody biomass imports.

Production processes in the US and Canada generally meets the stiff EU requirements of social and environmental sustainability, and would thus attract increasing demand from the EU, which would help the pellet industry grow in North America. However, the domestic markets in the US are large and set to grow rapidly for the same reason as in the EU. Moreover, with several Canadian provinces also planning to reduce their dependence on fossil fuel for heating, this would impact export prices and reduce their attraction as sources of pellets for markets in the EU. Pellet production on this continent is, therefore, unlikely to remain a major source for bioenergy in the EU for much longer.

Long, careful work to improving social and environmental sustainability is needed in Brazil before its natural advantages as biomass producer could bring large benefits to all stakeholders.

A large territory, excellent climate and soil conditions for biomass production together with good shipping connections to many countries in Europe makes Brazil a potentially great source for pellets for Europe. However, there have been serious concerns over the social and environmental sustainability of forestry and other land-based economic activities in the country. Fortunately, in recent years Brazil has taken transformational steps in deepening the roots of its democratic polity, resulting in enhanced social equity as well as taking strong measures to reduce deforestation and limit damage to its forests. As a result, the EU may now find it possible to further encourage and strengthen this process to enable the country to reach the requisite levels of sustainability. Of particular interest would be the production of wood pellets using sawdust from sawmills, secondary processing plants and forest harvest residues for which the common practice in Legal Amazon states still involves open air burning or disposal in stockpiles or landfills. Considering that Brazil produces 3.5 million tonnes of wood waste annually from harvesting its natural forests, it can be used to produce about 0.9 million tonnes of pellets, if only a quarter of the wood waste could be used. In addition, harvesting planted forests is also a significant source of woody residues. Harvesting eucalyptus plantations in Brazil leave about 5.7% of ligneous residues in the field and with an annual wood production of 90 million tonnes a potential annual supply of 5 million tonnes of pellets could be expected from this source. An advantage in Eucalyptus plantations is that it would be easier to establish sustainability and make the product eligible to export to the EU.

Brazil is the single biggest charcoal producing country in the world – accounting for 47% of the production in Latin America and the Caribbean in 2009 – and is used primarily for the production of pig iron in the country. A weakened demand in the wake of the economic downturn saw its production plummet from 8.4 million tonnes in 2008 to 5.1 million tonnes in 2009 with an equally sharp recovery in 2010. The evolving climate mitigation policies in Brazil are oriented towards increasing the proportion of charcoal used in blast furnaces to displace coal. This would further restrict Brazil's capacity to export charcoal to Europe. EU charcoal imports mainly come from Argentina, Cuba and Paraguay. However, charcoal from Latin America may not play any key role in the renewable energy mix of the EU.

The mean annual net primary productivity of tropical evergreen forests is 4.6 times that of Boreal forests and 2.4 times of temperate conifers. Producing biomass for energy in equatorial Africa thus has a natural advantage over Europe (see sustainability aspects in Chapter 5). These factors together with the geographical proximity to European markets should translate into good opportunities for the rural economies of a number of African countries, in particular the Congo Basin countries of Central African Republic, Democratic Republic of Congo, Equatorial Guinea, Cameroon, Gabon, Rwanda and Congo Brazzaville as well as other countries in the region such as Angola, Ghana, Nigeria, Ivory Coast, Tanzania, Kenya, Uganda, Mozambique and Zambia.

The economic opportunities offered by biomass exports have the potential of substantially reducing poverty in the rural areas and thus furthering the objectives of the Millennium Development Goals, to which the EU has a strong commitment. In recent years, Brazil, under its South-South cooperation policies, has initiated several measures aimed at improving the rural economy of Portuguese speaking countries of Africa; similar steps have also been taken by China and India in several countries of the continent which opens the possibility of enlarged collaboration for biomass production.

However, poor governance, a high incidence of corruption and the resultant chaotic forest management is a serious threat to the social, ecological and economic sustainability of large-scale forestry operations in many of these countries. Land grab for large-scale planting of trees for the supply of biomass for export is a particular concern, given the history of such acts in the past. The cost of improved governance by way of reducing such failures will be high and cannot be added to the cost of producing biomass by the private or public investors. The EU may have to invest substantially to create a favourable environment over at least limited parts of these countries from where biomass could be sourced. This is discussed in the next section.

No significant bioenergy imports from Asia-Pacific into Europe are likely as China and India constitute huge markets for the wood produced in the countries of the region.

2.

Conversion

2.1 Introduction

Forest biomass can be delivered in various physical forms and moisture content, and converted into many energy commodities such as heat, power or transport fuel. Diverse technologies to convert the feedstock into an energy carrier can thus be applied, depending on the feedstock quality, its characteristics and the desired product. Alternative conversion technologies differ in the feedstock needed, cost, conversion efficiencies, capacities or emissions. Choosing the right technology in a specific region depends not only on its energy requirements but also on the local conditions such as infrastructure, feedstock accessibility, fossil-fuel use and the prices or policies applied. This chapter presents an overview of the actual and promising technologies for the conversion of forest biomass into energy carriers; it is divided into the following three sections: (1) heat; (2) power; and (3) transport fuel.

2.2

Heat

Lennart Gustavsson and Claes Tullin

In 2010, 47% of the EU's final energy consumption was in the form of heat. The largest uses were for space heating and for industrial applications.

Biomass is by far the dominating renewable energy source for heating and has the largest potential from a European 2030 perspective.

The transition of the Swedish energy system, where bioenergy today accumulates to about a third of the energy use, is a good example of how biomass can replace fossil fuels for heating.

Forest biomass fuels derives to a large extent from forest residues (slash from felling and thinning) and by-products such as bark, sawdust and shavings from the pulp, paper and saw-mill industries. Pellets and briquettes are produced as refined fuels from sawdust and shavings. Firewood is used in stoves and boilers for domestic heating.

Biomass can be used directly as a major heat source in single or multifamily houses, or it can be used to produce heat in smaller or larger district heating systems. These boilers can provide heat to several thousand households. Very high system efficiencies can be obtained, typically over 90%. In larger units, heat production is often combined with power generation in combined heat and power (CHP) plants (discussed in Chapter 2.3). Future developments include even more complex technologies – for instance, energy

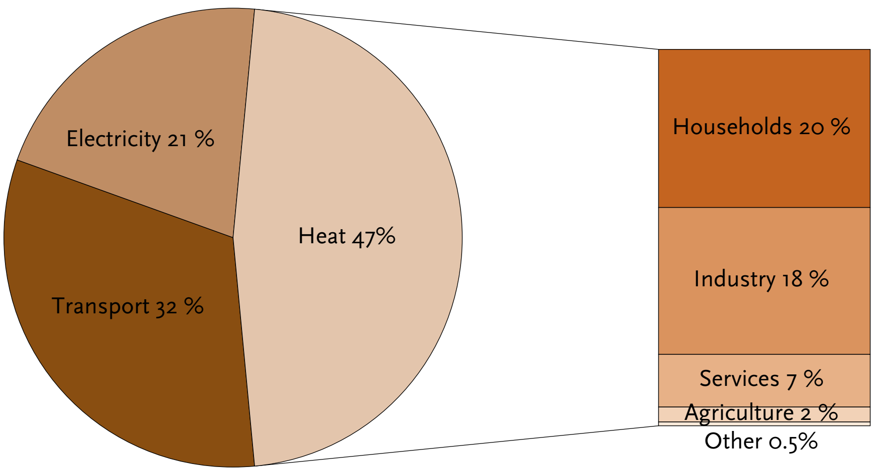

Figure 5. Final energy use in EU-27 in 2010 by type of energy and final energy use for heat by individual sector. Source: European Technology Platform on Renewable Heating and Cooling.

combines for biofuel production – but it will always be important to integrate the use of heat with electricity or fuel production in order to ensure high system efficiencies.

Biomass is available in many different qualities, coming in various physical forms (from sawdust to whole trees) and with moisture content ranging from well below 10% to almost 60%. In addition, the chemical composition and ash content of different types of biomass varies widely, with the possibility of contamination during collection and handling adding to its variability.

Fuel pre-treatment may include sorting and classification, reducing impurities, baling and bundling, reducing the size to chips for example, drying and producing pellets or briquettes. A fuel with reasonably high quality can decrease the plant investments costs and operation costs. Also, storage and handling costs may be reduced.

Heat demand varies seasonally, which affects storage requirements. Storage design and handling procedures should take into account that biological and biochemical degradation as well as chemical oxidation (in the case of dry fuels) may lead to potentially hazardous levels of carbon monoxide and also the risk of self-ignition.

A boiler is normally designed for a certain range of fuel moisture. Drying is normally achieved relatively cheaply by outdoor storage, but can also form part of the fuel-production process, for example for pellets. In plants where moist fuels are used, the thermal efficiency can be increased by flue-gas condensation. In this way, a significant amount of the heat that is normally lost in the hot and humid flue gases is recovered.

Biomass in the form of pellets is a well-defined, high-quality fuel with high energy density and low ash and moisture content. Pellets are often produced by compressing sawdust into cylinders with a diameter of 6–10 mm. Today, pellets are a globally traded commodity. For domestic heating and small-scale district heating, pellets are fired as such in specially designed burners or boilers. On the large scale, pellets are often ground and used in large, pulverized-combustion steam generators that are either dedicated to biomass or co-fire biomass with another fuel, typically pulverized coal.

During the twentieth century, wood for home heating was largely replaced by fossil fuels. As a result of the later year's phasing-out of fossil oil, wood has however made a comeback. It is used as wood logs or briquettes in stoves, boilers and open fireplaces, with or without inserts. It is also consumed in the form of pellets in automatic boilers and stoves, where the fuel is fed automatically to the fire according to the current heating demand.

Old types of log-wood boilers and stoves can cause significant emissions of unburned hydrocarbons and particles, which may lead to local environmental disturbances and cause health problems. An impressive build-up of knowledge concerning the basic processes in biomass combustion has led in recent years to the development of new products with much lower emissions of unburned hydrocarbons, particulate matter and carbon-monoxide (Figure 6).

In order to minimize emissions and maximize energy efficiency, a log-wood boiler should operate at its design conditions. Normally, this means that the heat load should be close to the boiler´s maximum and also relatively stable. However, this is not the case for the heat load of a house over the heating season – it is recommended to use a heat accumulator tank where heat from the combustion is stored in hot water and thereafter dissipated to the heating system according to the momentary demand. This system is

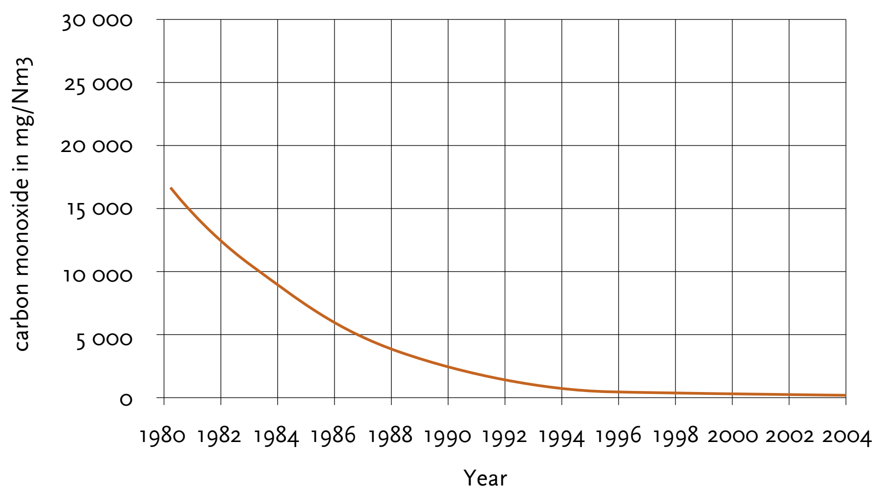

Figure 6. Measured emissions of carbon monoxide (CO) in type testing of wood boilers at the BLT Wieselburg test center. Source: BIOENERGY2020+ GmbH.

now standard in the Nordic countries and is spreading to other European markets. The boiler only needs to be fired once (possibly twice) per each day during winter and only two to three times a week during the spring and autumn.

Another way to ensure good emission and efficiency data is to make more use of modern measurement and control technology. A 'simple', but efficient way is to copy car-engine technology, where the excess air in the combustion chamber is measured by a lambda probe and the amount of air is continuously adapted to optimum conditions. This means that factors such as momentary heat load, and fuel properties like moisture, log size and draft conditions are adjusted automatically to achieve optimum combustion results. Boilers operating with such equipment are well established on the European market today.

A most important trend is the establishment of pellets as a common domestic fuel. Wood pellets have a number of advantages. They are normally of constant size and quality, which allows the boiler or stove to operate automatically, thus facilitating good combustion quality and low emissions. It has also opened up a new global commodity market since pellets are relatively easy to transport. The home heating market for pellets is most developed in Austria, Denmark, Germany and Sweden.

The first generation of pellet-combustion equipment was pellet burners, which were developed in Sweden to replace oil burners. They were mounted in existing oil or multi-fuel boilers in order to decrease heating costs. A driving force was the introduction of the Swedish carbon dioxide tax on fossil fuels. Today, pellet burners account for most of the domestic pellet use in Sweden.

Currently, the dedicated pellet boiler unit is the most common way of using wood pellets – the boiler is entirely optimized to the characteristics of pellets. Automatic load control, ash removal and cleaning of the heat absorbing surfaces in the boiler are features that make the pellet boiler a most attractive alternative for many home owners. Also, the fuel can be delivered in bulk trucks via a flexible pneumatic pipe to a 5–10 m^3 storage bin, which makes fuel handling very convenient.

Stoves, open fires and inserts are room heaters that heat the air in the living area directly without any use of a heat distribution system. They come in a large variety of types, materials and designs. An important feature is that the appliance must have an aesthetic appeal. For this reason and to meet the desired heating characteristics, a number of materials are used such as cast iron, steel plate, ceramics and soapstone.

The improvements in thermal efficiency and the reductions in emissions from room heaters have also been significant. The measures taken involve increasing the combustion temperature through more insulation, dividing the combustion air supply in stages and optimizing the geometry of the fire chamber. In order to meet the decreasing heat loads of today´s and future low-energy houses, continuous improvements have taken place in order to make clean combustion also with as low as part-loads as possible. Another approach to meeting the low-energy trend is to use 'slow-heat release appliances' such as tiled stoves and stoves made of soapstone. In these, the heat from one or two large fires is stored in the large mass of the appliance (up to 2,000 kg) and then slowly released over a day or two into the room.

The advantages of wood pellets as a fuel are also exploited in pellet stoves. As they are normally situated in the living area, the stove's fuel reservoir must be filled manually from small sacks of pellets. Typically, refilling is only required a few times a week. The advantages of automatic output control, often combined with fan-assisted warm air distribution, is thought to more than compensate for the labour involved in the fuel supply.

Another recent development is the combined biomass and solar system, which combines a biomass boiler with several square meters of solar heating panels and a heat accumulator tank. Heat from the panels is transferred to the tank according to the varying solar influx, and is supplemented by heat from the biomass boiler when needed. Hot water, typically produced by a coil in the tank, is then extracted from the tank to the radiator system according to the needs of the house. While solar heat is usually adequate to supply hot water during the summer, its contribution can be significant during the heating season.

Biomass is used not only for small-scale domestic heating, but also for industrial heating and large-scale district heating purposes. In some European countries, e.g. Finland and Sweden, a large part of the biomass use for energy purposes traditionally takes place in the sawmills and the pulp and paper industry, where waste and residues are used for internal heat and power generation.

In the pulp and paper industry, the combustion of biomass forms an integral part of the main process, in which wood is de-lignified and the cellulose is converted into pulp. Heat generated through the combustion of biomass in kraft recovery boilers and causticizing ovens is key to recovering process chemicals so that today's pulp mill is effectively a closed loop system with no chemical losses.

For heat production on an industrial scale, grate technology is common – the fuel is continuously fed onto a grate through which primary air is introduced. However, meeting today's stringent emission and efficiency requirements poses a challenge to manufacturers of grate-technology as the grate and combustion chamber requires optimal geometrical and thermal design.

On a larger scale, fluidized-bed technology and pulverized combustion units are also used, and are often configured to produce combined heat and power (CHP). The technology of these is discussed in the next chapter.

In addition to use by wood-related industries, biomass fuels may be used in a number of other industrial applications such as hot water and steam production as well as

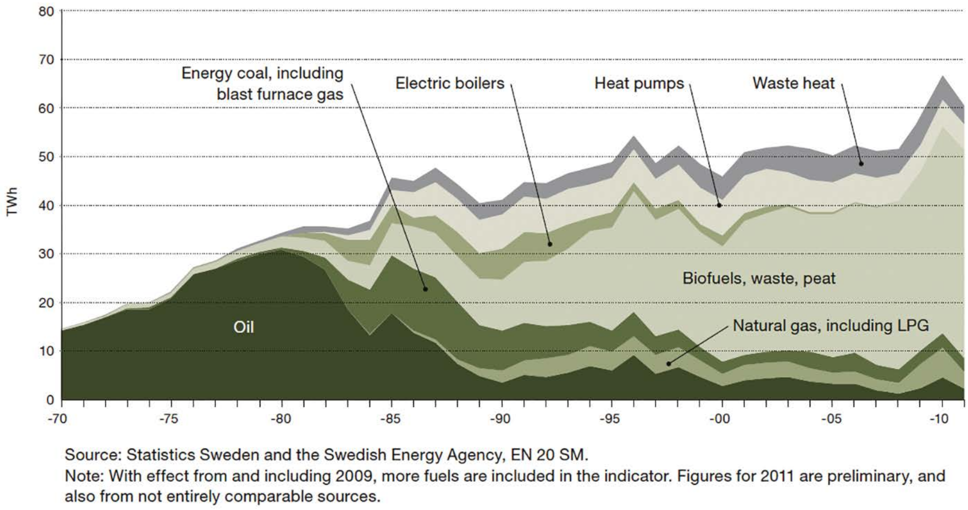

Figure 7. Development of the use of the energy sources for district heating in Sweden between 1970 and 2011.

direct process heating. Examples of enterprises where biomass may be used much more than they are at present are food industries, greenhouses, laundries, steel-manufacturers, cement ovens and asphalt cookers.

In Sweden, a strong expansion of district-heating grids took place during the 1960s and 1970s in order to reduce air emissions and improve energy efficiency. The oil crises, calling for less dependency on oil, as well as the recent response to concerns over climate change have triggered an interest in replacing fossil fuels by renewable and low-carbon bioenergy. In 1991, a carbon-dioxide tax on fossil fuels was introduced, which formed a strong incentive to expand the use of bioenergy for district heating (Figure 7). Between 1970 and 2010, district heating in total has grown from 15 TWh, completely covered by fuel oil, to above 60 TWh, met 7% by bioenergy. Today, there are some 500 heating plants running on biomas fuels, each delivering more than 2 GWh a year. The use of oil is negligible.

Consequently, biomass-based district heating is expected to expand significantly within the European Union. An interesting alternative for the future is also the concept of combined district heating and cooling. By using surplus heat in a district-cooling grid, energy consumption can be reduced significantly in many cities compared with electricity-driven equipment. District cooling also helps reduce electricity peak loads during the summer, which are increasing due to growing cooling demands throughout Europe, in particular in southern Europe. This, in turn, reduces the need for investments in new power generation and network capacities.

Recommended reading

European Technology Platform on Renewable Heating and Cooling 2013. Strategic research and innovation agenda for renewable heating and cooling, Brussels, Belgium www.rhc-platform.org.

Andersson, K. 2012. Bioenergy – the Swedish experience. Swedish Bioenergy Association, Svebio, Stockholm, Sweden. 80 p.

Obernberger, I. and Thek, G. 2010. The Pellet Handbook, The production and thermal utilization of biomass pellets. Erathscan, London, UK. 592 p.

van Loo, S. and Koppejan, J. 2010.The Handbook of biomass combustion and co-firing. Earthscan, London, UK. 464 p.

2.3

Power

Stefano Consonni

The production of electricity based on biomass in the European Union increased by almost four-fold between 2000 and 2012, the highest rate of growth after wind power. There are a diverse number of conversion routes each with its own characteristics. This section presents an overview of the mature as well as several promising new technologies.

Combustion

Combustion-based plants comprise the overwhelming majority of biomass-fired power plants. The plant concept is very similar to the one adopted in large power stations fired with solid fossil fuels like coal or lignite, even if the specific features of the biomass feedstock and the much smaller scale dictate significant differences. The energy-conversion process comprises: 1) combustion, whereby chemical energy stored into biomass is converted into heat via exo-thermic oxidation reactions; 2) the transfer of heat from the flue gases generated by combustion to the working fluid of a thermodynamic cycle; 3) the conversion of heat into power by means of the thermodynamic cycle; and 4) the discharge to ambient air or water of the fraction of heat which, due to thermodynamic constraints, cannot be converted into power (see Figure 8).

The properties of biomass, which generates flue gases with high contents of dust and possibly corrosive substances, restrict the choice of the thermodynamic cycle to 'externally-fired' systems. This is most conveniently carried out in a closed-loop Rankine cycle, whereby the heat transferred by the flue gases evaporates a fluid at high pressure, which then expands into a turbine; the low-pressure vapour discharged from the turbine is turned into liquid in a condenser, then pumped back to the initial evaporation pressure to start a new cycle.

For power outputs above a few thousands kilowatts, water is by far the preferred working fluid. The resulting steam rankine cycle is similar to the one adopted in fossil-fuel-fired steam plants, even if the much smaller scale of biomass-fired plants leads to more moderate design parameters and simpler cycle configurations. For power outputs of up to about 2 MW, organic rankine cycles (ORC) tend to prevail because carbon-based working fluids allow a more favourable turbine design and better performance.

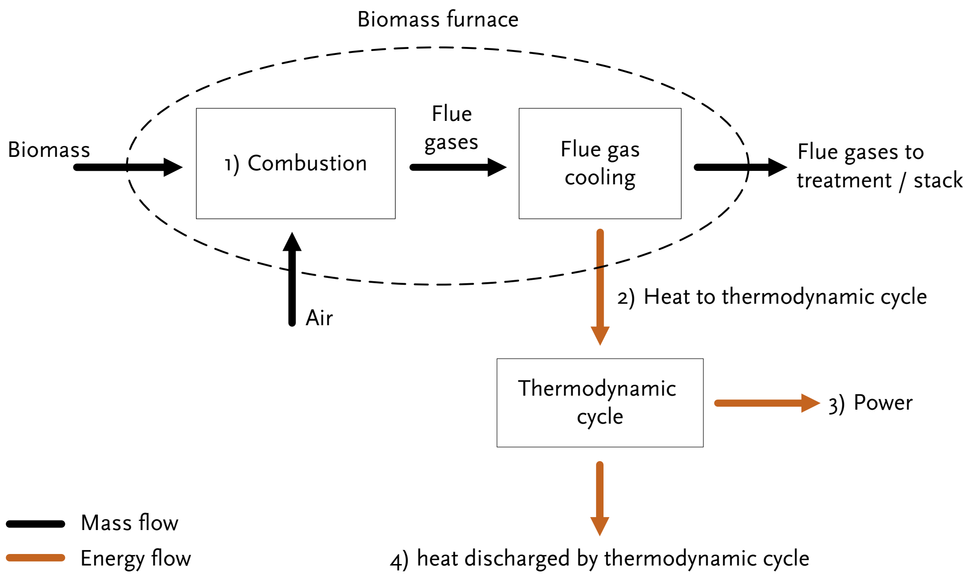

Figure 8. Schematic of a biomass combustion power plant. The thermodynamic cycle can be a steam rankine cycle, an organic rankine cycle (ORC), a gas turbine cycle or a stirling cycle. When the heat discharged by the thermodynamic cycle is used for commercial purposes, the plant is referred to as 'cogeneration' or a combined heat and power (CHP) plant.

The alternative to the rankine cycle is the externally-fired gas cycle, in which the working fluid always remains in the gas phase. Depending on the type and sequence of transformations undergone by the gas, the cycle is named either Joule or Stirling. In all cases, however, externally-fired gas cycles are seriously hampered by the very high temperatures that must be endured by the materials exposed to the biomass combustion products. As a consequence, gas cycles are currently not an industrially viable option.

Rather than being discharged to the ambient air or water, part or all of the heat discarded by the thermodynamic cycle may be used to meet the needs of a nearby industrial process or to provide heat and domestic hot water to buildings via a district heating system. In this case, the energy conversion process is named 'cogeneration' and the plant referred to as a combined heat and power (CHP) plant. Cogeneration allows a more thorough utilization of the energy embodied in the biomass feedstock.

The distinctive component of biomass combustion power plants is the biomass boiler, which carries out two of the basic processes described above: combustion and the transfer of heat from the flue gases to water and steam or, as it generally happens in organic rankine cycles, to an intermediate heat carrier (e.g. diathermic oil) which then releases heat to the ORC working fluid.

The most common arrangement, a grate combustor, consists of a sloping, moving grate over which biomass slowly travels until it is completely combusted. Combustion air is injected underneath the grate while the ashes left after the entire combustible fraction has been oxidized are discharged at the end of the grate. The grate is surrounded by tubes carrying the fluid (water, steam or diathermic oil) which picks up the heat released by the flue gases.

The most widespread alternative is the fluidized bed, in which biomass particles are suspended in a stream of air (and possibly flue gases) that maintains them in turbulent motion until they are combusted. This takes place in a vessel with the walls covered with tubes filled with water and/or steam that carry away the heat generated by combustion.

Biomass combustion generates flue gases with high contents of dust and a wide range of pollutants such as hydrocarbons and acidic gases. This is why modern plants must necessarily include a flue-gas cleaning system that removes any solid particles from the flue gas and, in many instances, scrubs out gaseous contaminants such as nitrogen oxides, sulphur oxides and hydrochloric acid.

Gasification

Gasification is the process where a solid (or heavy liquid) feedstock is converted into a combustible gas by the partial oxidation of the atoms that constitute it. As in combustion, the physical and molecular structure of the feedstock is taken apart by a complex combination of chemical reactions and thermal processes that generates a gas comprising relatively few simple molecules. Unlike in combustion however, the scarcity of oxygen prevents the formation of fully oxidized species. Rather than being completely converted to CO_2, a large part of carbon in gasification is converted into CO or other species with low (or zero) oxygen: methane, light hydrocarbons and tars, etc. Hydrogen is converted both to H_2O, and to H_2. Sulphur is converted to H_2S, COS or other reduced species. Nitrogen may generate NH_3 and cyanides (HCN and the like). The gaseous flow rich in CO and H_2 generated by gasification is called 'synthetic gas' or 'syngas', a name which signifies the difference between such combustible gas and the fossil 'natural gas' or the 'biogas' rich in CH_4.

In gasification, only a fraction of the fuel chemical energy goes to increase the temperature of the syngas and the ashes; a relevant fraction stays in the syngas as chemical energy. Such syngas chemical energy can be used to produce power or transferred to a marketable fuel (methane, hydrogen, methanol, FT-diesel, etc.). The amount of the initial chemical energy in the feedstock that goes into syngas chemical energy depends on the gasification technology. This is measured by the cold gas efficiency (CGE), which is defined as the ratio between the heating value of the syngas and the feedstock flows.

The basic rationale of gasification is twofold. First, syngas is a much 'better' fuel than the solid (or heavy liquid) feedstock, thereby allowing the use of high-efficiency, low-emission internal combustion systems for the production of power. Second, a large variety of established chemical processes are available for the conversion of syngas either to marketable fuels or to chemicals.

In a gasification-based power plant, the actual achievement of efficiencies higher than those of combustion-based plants depends on whether the superior performances of the internal combustion system compensate for the losses brought about by gasification.

Similar considerations hold for specific investment costs [EUR per kW installed], which are lower for internal combustion systems but must be weighed against the costs of the gasification section. The achievement of lower emissions relies mainly on the clean-up of syngas ahead of its use in the internal combustion system. Reliability tends to be hampered by high plant complexity and limited operating experience.

When syngas quality is very poor (e.g. gasification of waste), gasification may be coupled to an externally-fired steam plant to avoid the challenges of meeting the specifications of internal combustion engines or gas turbines. Such configuration however, fails to capture one of the basic goals of gasification, i.e. the use of internal combustion engines, and typically gives efficiencies lower than those of combustion-based plants.

Gasification technologies can be classified according to a number of criteria.

1) Type of fluid-dynamic arrangement of the gasifier:
- fixed bed, where relatively large pieces of feedstock lay on a grate until they are gasified;
- fluidized bed, where small pieces of feedstock are kept afloat by the gasifying agent;
- entrained flow, where pulverized feedstock is gasified in a sub-stoichiometric flame.

2) Type of oxidant:
- air-blown;
- oxygen-blown.

3) Operating pressure of the gasifier vessel:
- atmospheric;
- pressurized.

4) Heat supply mode:
- directly heated, where the heat needed for the endothermic gasification reactions is supplied by the partial oxidation of the feedstock;
- indirectly heated, where heat is supplied by a heat-exchange mechanism.

In addition to air or oxygen, steam is also required to help fluidizing the gasification reactor and increasing reactivity. Table 3 compares the main features of the three basic fluid-dynamic arrangements.

Most biomass gasifiers developed so far are either fixed bed or fluidized bed, air-blown, atmospheric or directly heated. The use of biomass in entrained flow gasifiers is hindered both by the difficulty to mill it to very fine particles and by its poor heating value, which prevents the attainment of high temperatures. These limitations may be overcome by torrefaction (upstream of the gasifier) or by co-gasification with other suitable feedstock. The preference for air-blown arrangements follows the modest scale typical of biomass plants, which makes the cost of the oxygen plant hard to justify. Although highly desirable – especially when power is generated by a combined cycle that requires syngas at 25–50 bar – pressurized gasification poses substantial challenges for the feed system and its auxiliary power consumption.

The technology of choice for power generation depends on the scale of the plant. Up to a power output of a few MW, the Otto reciprocating engines also used for biogas

Table 3. Main features of the three basic gasification technologies when directly-heated.

Type of gasifier	required feed size	syngas temperature	Cold Gas Efficiency	oxidant demand	steam demand	tar in syngas	carbon in ashes	through-put
Fixed bed	medium (10–100 mm)	low-medium (450–650°C)	high	low	medium-high	high	medium	low
Fluidized bed	small (5–20 mm)	medium (850–1,000°C)	medium	medium	low-medium	low	medium-high	medium
Entrained flow	very fine (< 0.1 mm)	high (1,250–1,600°C)	low	high	low	zero	low	high

applications are the most suitable choice. They are typically coupled with atmospheric-pressure, fixed-bed gasifiers which, due to their simplicity, allow limiting investment costs. For large power outputs (above 20–30 MW), biomass integrated gasification combined cycles (BIGCC) have higher efficiency and lower cost electricity, although they cannot be considered a commercial technology to date.

Syngas clean-up is the key to achieving reliable operation. High concentrations of tar and alkali make this task particularly challenging and are the focus of extensive research. Emissions are determined both by syngas clean-up and by power technology. In BIGCCs, the stringent requirements imposed by the gas turbine on the quality of clean syngas warrant very low emissions of most pollutants, with the only possible exception of NO_x.

Pre-treatment by torrefaction

Torrefaction is a mild pyrolysis process (200–350°C) that resembles the roasting of coffee beans in many aspects. By combining torrefaction pre-treatment with compaction into pellets or briquettes, the quality of the biomass feedstock is significantly enhanced as is the efficiency of the biomass supply chain downstream of torrefaction/pelletization. While the development of torrefaction technologies is mainly driven by the desire from large coal power production utilities to increase the firing and co-firing of biomass materials, the benefits could well be exploited in all biomass conversion systems.

By torrefaction and subsequent compaction, the biomass bulk energy density, calorific value, water resistance and friability are significantly increased, while the moisture and oxygen content are reduced.

The final powder fuel may also resemble coal powder in terms of feedability and process behaviour.

Today, several industrial-scale torrefaction plants are up and running. However, costs still need to be reduced, technology improved and availability increased to pave the way for commercial torrefaction.

Recommended reading

Rosendahl, L. (ed.). 2013. Biomass combustion science, technology and engineering. Woodhead Publishing, Cambridge, UK. 320 p.

Van Loo, S. and Koppejan, J. (eds). 2008. The Handbook of biomass combustion and co-firing. Earthscan, London, UK. 442 p.

Yin, C., Rosendahl, L. A., and Kær, S. K. 2008. Grate-firing of biomass for heat and power production. Progress in Energy and Combustion Science 34(6):725–754. doi:10.1016/j.pecs.2008.05.002.

Craig, K.R. and Mann, M.K. 1996. Cost and Performance Analysis of Biomass-Based Integrated Gasification Combined-Cycle (BIGCC) Power Systems. Report NREL/TP-430-21657. Oct. 1996. National Renewable Energy Laboratory, CO, USA. 70 p.

Knoef, H.A.M. 2012. Handbook on Biomass Gasification, Second Edition. BTG Biomass Technology Group. 500 p.

Kumar, A., Jones, D.D. and Hanna, M.A. 2009. Thermochemical Biomass Gasification: A Review of the Current Status of the Technology. Energies 2: 556–581. doi:10.3390/en20300556.

Nordin, A. The dawn of torrefaction. 2012. BE Sustainable Magazin 0:20–23.

2.4

Transport fuel

Frederik Ronsse, Henning Jørgensen, Ingmar Schüßler and Rikard Gebart

Worldwide, the use of transport fuel derived from biomass increased four-fold between 2003 and 2012. Mainly based on food resources, these conventional biofuels did not achieve the expected emission savings and contributed to higher prices for food commodities, especially maize and oilseeds. Advanced biofuels based on forest biomass are not yet being produced on a large scale, but are expected to have a better life-cycle emission profile than conventional biofuels. The pathways from feedstock to advanced biofuel are diverse in respect to capacity, technology and final product. Three promising conversion technologies are presented below: pyrolysis, biochemical conversion and gasification.

Pyrolysis

Pyrolysis is a thermochemical conversion technique, in which biomass is decomposed at elevated temperatures (> 300°C) in an oxygen-free environment. Pyrolysis results in three distinct product fractions: char, non-condensable gases and condensable vapours. After condensation, a dark, combustible liquid is obtained called 'pyrolysis oil' or 'bio-oil'. The yield and composition of these three product fractions depend on the heating rate and temperature applied in pyrolysis. Based on these process conditions, differentiation can be made between torrefaction, slow pyrolysis, fast pyrolysis and gasification (Table 4).

In fast pyrolysis, process conditions are selected to obtain a maximum bio-oil yield, including: moderate pyrolysis temperatures (around 500°C); rapid heating rates (>100°C min^{-1}); short biomass residence times (0.5–2 s); small particle size to support high heating

Table 4. Typical product yields in wt%, for different types of pyrolysis processes.

	Pyrolysis process type			
	Fast pyrolysis	Carbonisation (slow pyrolysis)	Gasification	Torrefaction
	T ~ 500°C, fast heating, short vapour residence time (~1 s)	T > 400°C, slow heating, long biomass residence time (minutes to hours)	T ~ 750-900°C, Oxygen-limited environment	T < 300°C, long biomass residence time (up to 1 hour)
Liquids (bio-oil)	75%	30%	5%	5%
Non-condensable gases	13%	35%	85%	15%
Char or solids	12%	35%	10%	80%*

* Torrefaction is a form of partial pyrolysis and the obtained solid product is not actual char.

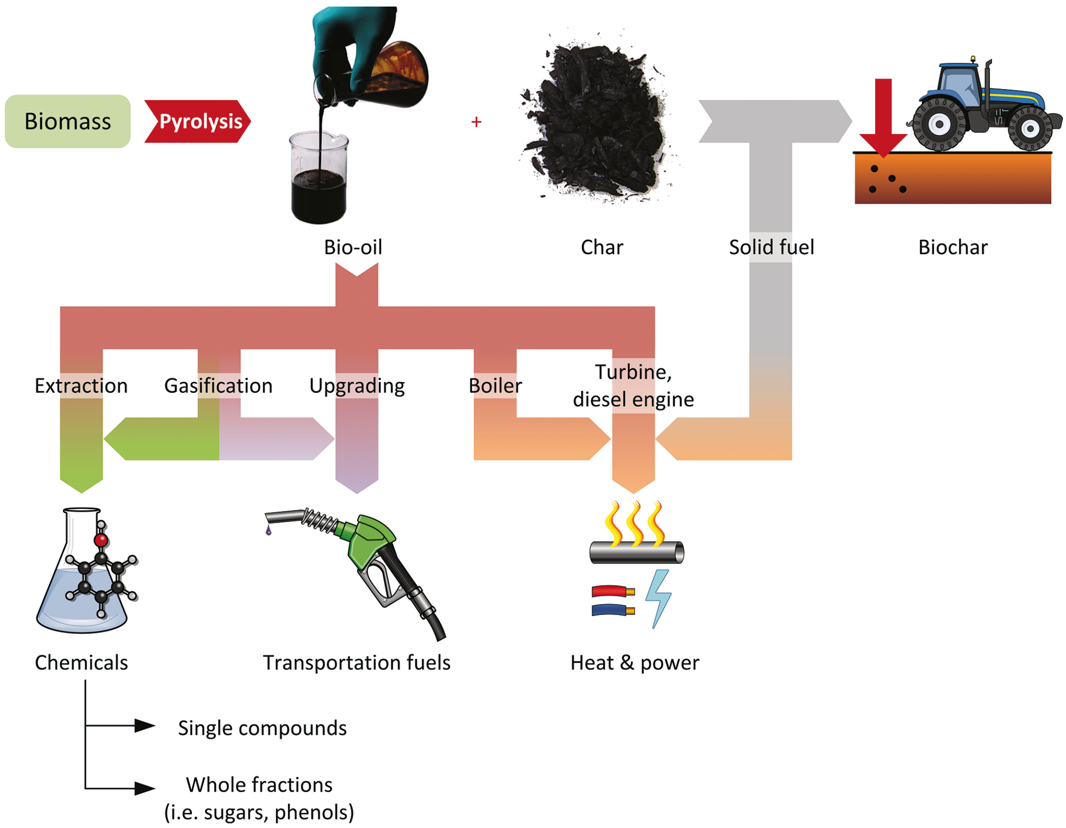

Figure 9. Applications of fast pyrolysis bio-oil and char.

rates (typically less than a few millimetres); and rapid cooling or quenching of the pyrolysis vapours. Under these conditions, bio-oil yields of up to 60–75 wt% (on dry biomass feedstock basis) can be obtained. The produced gases and char may be burned on-site to provide process heat.

Fast pyrolysis differs from slow pyrolysis in that the latter aims at achieving a maximum char yield of up to 35 *wt%*. Traditionally, slow pyrolysis has been used in charcoal production and more recently, in the production of carbon-rich soil amendments, collectively known as 'biochar'. Fast pyrolysis bio-oil is highly oxygenated and approximates the elemental composition of the biomass feedstock. Chemically, it is a complex mixture of water (15 to 30 *wt%*) and several hundreds of organic compounds, although the exact composition depends on the feedstock and process conditions. Bio-oil is highly corrosive and has a heating value ranging from 17 to 20 MJ/kg, which is significantly lower than the heating value of petroleum. A final drawback of bio-oil is its instability during storage.

As bio-oil is combustible and can serve as a substitute for fossil fuels in a variety of static applications (Figure 9) including boilers, turbines and diesel engines.

However, modifications are required to cope with the corrosive nature, lower calorific value, poor ignition properties and the higher viscosity of bio-oil.

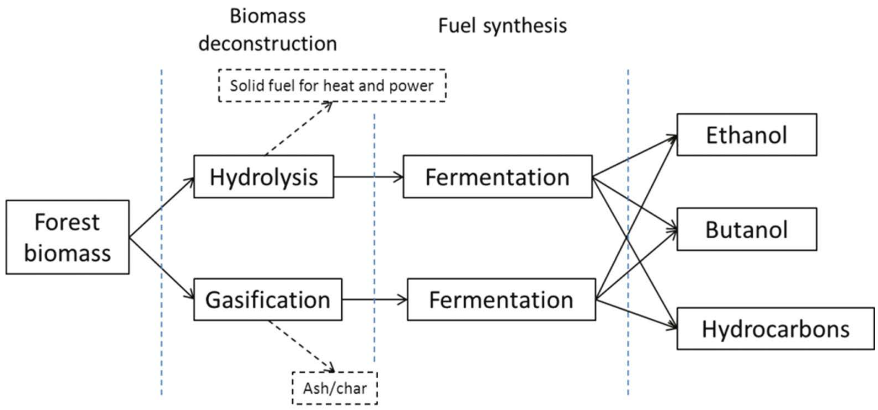

Figure 10. Schematic representation of forest biomass conversion via fermentation into liquid transport fuels.

Since the negative properties of pure bio-oil hamper its direct use in internal combustion engines, there is a growing interest in upgrading pyrolysis vapours or bio-oil for co-feeding into existing petrochemical refineries or blending in today's transportation fuels. Most of today's research activities in bio-oil upgrading revolve around the use of catalytic fast pyrolysis or bio-oil hydrodeoxygenation (HDO).

Another potential application is the production of renewable chemicals from bio-oil.

However, since pyrolysis bio-oil contains between 200 to 300 chemical compounds, the isolation and purification of individual (valuable) chemicals is technically difficult and expensive. Extraction strategies therefore revolve around the use of bio-oil derived fractions, rather than individual compounds.

Fractions of chemicals that can be easily extracted include wood flavour, phenolics (e.g. for use in resins), anhydrosugars (e.g. for use in fermentation) and carboxylic acids. The gasification of bio-oil into syngas may provide an alternative to cope with the complexity of bio-oil for the production of platform chemicals.

Production of liquid transportation fuel via biochemical conversion

The production of liquid fuels via biochemical conversion involves two key steps: 1) deconstruction of the biomass into sugars or gaseous components; and 2) fuels synthesis via microbial fermentation (Figure 10). The biomass deconstruction can proceed via two main routes. The hydrolysis route is based on liberating sugars making up cellulose and hemicellulose, which is 70–80% of the biomass, either by chemical or thermo-mechanical means and typically combined with enzymatic hydrolysis. Using various microorganisms, the sugar can then be fermented into various products such as liquid biofuels. The solid residue left after hydrolysis (mainly lignin) is an excellent solid fuel that can be used for heat and power production. The gasification route is based on gasifying the biomass. The goal is to convert all of the biomass (except ash) into carbon

Table 5. Advantages and limitations of the most promising fermentation derived biofuels to date.

Fuel	Advantages	Limitations
Ethanol	• Well proven and robust technology • High yields and high productivity • Relatively low production costs • Ethanol already used widely in gasoline blends	• Low-value product • Low energy density • Water soluble and hydroscopic
Butanol	• Proven technology • Higher energy density than ethanol • Fully miscible with gasoline	• Lower yields, lower productivity • More costly product recovery • Technically more challenging technology
Hydrocarbons (isoprenoids, farnesene)	• High grade fuels (e.g. jet fuel) • High energy density • Fully compatible with existing fuels (drop-in)	• New and unproven technology • Low yields and productivity • Technologically challenging • High production costs

monoxide, carbon dioxide and hydrogen. Hydrogen is by itself a possible fuel while carbon monoxide can be fermented into various biofuels (Figure 10). Both routes offer a great deal of flexibility and can be integrated into various biorefinery concepts to utilize waste streams or valorize by-products. Finally, the choice of products from the fermentation platform is huge and not only restricted to biofuels – they could be other platform chemicals, plastic precursors or even food or feed products.

For both routes, the main issues are related to the operating cost, yield and energy balance of the deconstruction step as well as the production of various degradation products that can inhibit the fermenting microorganism. The hydrolysis route has been the predominant choice in connection with fermentation because many traditional fermentation processes are based on sugars as the carbon and energy source. This simplifies process development, especially the fermentation step. While several technologies have been developed and demonstrated, wood biomasses, in general, are regarded as being difficult to hydrolyze compared with agricultural residues. Examples of active companies are Borregaard in Norway, SEKAB in Sweden and Lignol in Canada.

Forest biomass is well suited for gasification, which has been demonstrated on the industrial scale (see Chapter 2.3). The fermentation of syngas is less developed, both regarding suitable microorganisms and fermentation equipment.

One main issue is the possible need for gas cleaning prior to fermentation. LanzaTech, a New Zealand company, has successfully demonstrated the production of ethanol from carbon monoxide.

The energy balance and economic feasibility (on the large scale) is better for the gasification rather than the hydrolysis route. Data are too limited regarding the overall process using gasification to allow comparison between the two routes. At present, the most promising liquid biofuels made by biochemical conversion are ethanol, butanol and, very recently, hydrocarbons (e.g. isoprenoids or farnesene). The advantages and limitations of these biofuels are listed in Table 5.

Ethanol has been produced by fermentation on an industrial scale for centuries. The technology of fermenting sugars into ethanol is robust and optimized, and is similar to the production of the current fuel ethanol from sugar and starch. Ethanol has been produced as a by-product from pulp and paper mills only by few companies such as Borregaard in Norway and Tempec in Canada. The direct conversion of biomass to ethanol via hydrolysis is not carried out commercially, but has been undergoing trials for a number of years.

Butanol also has a long history of industrial production via fermentation of biomass (the ABE process). The technology is proven and well-known, but productivity and yields are low. The toxicity of butanol towards the fermenting micro-organism is the main problem constraining its production. As a fuel, butanol has several advantages over ethanol: its energy density is higher and it is more compatible with fossil fuels. Companies such as DuPont, BP, Gevo and Butalco have plans to start the production of butanol from biomass.

Hydrocarbons produced directly by fermentation have only very recently received attention as potential fuels. It is a diverse group with isoprenoids and farnesene, in particular, being key products. Their fuel characteristics are superior – the possibility to use them as jet fuel replacements makes them commercially interesting. As the fermentation process is more complex, yields and productivity are low and thus production costs are currently high. Amyris is one of the companies that has trialled the production and testing of farnesene for aviation fuel.

In general, ethanol has the best energy and Greenhouse Gas (GHG) balance and lowest production costs. Due to lower yields and increased operation and recovery costs, the energy and GHG balance as well as its costs are less favourable for butanol and for hydrocarbons, in particular. Butanol and especially hydrocarbons might command a higher selling price than ethanol.

Production of transportation fuel through gasification

The production of transport fuels via thermo-chemical conversion is achieved through further processing the syngas from gasification. It is either possible to directly extract and use hydrogen from the syngas, or convert carbon monoxide and hydrogen at elevated temperatures and by the use of catalysts into nearly any desirable gaseous or liquid hydrocarbon. Regarding the latter, the main focus in research and industry at the moment is on methane conversion, methanol and dimethyl ether (DME) production, and Fischer-Tropsch (FT) synthesis for the production of automotive fuels and waxes.

Due to the requirements of these products and the conversion catalysts, the variety of possible gasification technologies presented in Chapter 2.3 is limited. Furthermore the syngas still has to undergo sufficient pre-treatment before conversion.

The syngas pre-treatment mainly involves cleaning dust, tar and non-tar components such as sulphur or chlorine from the gas as well as the subsequent gas-conditioning stages.

Cleaning has to be more sophisticated than for gasification-to-power applications since the syngas conversion catalysts demand much higher gas purities than combustion chambers or internal combustion engines.

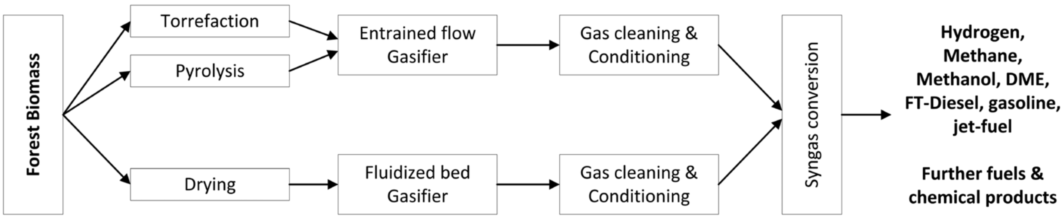

Figure 11. Most likely conversion paths from biomass to transportation fuels via gasification.

Table 6. Typical characteristics of gasifier types.

<table>
<tr><th>Entrained flow gasifier (oxygen blown)</th><th>Fluidized bed gasifier (oxygen blown)</th><th>Fluidized bed gasifier (steam blown)</th></tr>
<tr><td colspan="2">• Simpler in construction design.
• Easier to upscale.
• Easier to pressurize (eliminates need to pressurize syngas afterwards).
• Increase in hydrogen ratio possible through steam addition (in such an amount that allows required gasification temperatures to be reached).</td><td>• High hydrogen ratio in syngas (reduces efforts needed to set the desired H_2-CO ratio).
• Usually high cold gas efficiency.
• No energy-demanding air separation unit needed.</td></tr>
<tr><td>• Tar-syngas through high reaction temperatures above 1,200°C (reduced efforts in gas cleaning).
• Convenient when aiming for liquid fuels.</td><td colspan="2">• Significant amount of methane (and other hydrocarbons) in syngas through lower reaction temperatures (around 800–900°C).
• Primary cleaning and reforming stages could be included in the gasifier by choosing catalytic-bed materials.
• Convenient when aiming for methane conversion.</td></tr>
</table>

Syngas conditioning usually comprises a water-gas shift reaction, in which the hydrogen content is increased by the reaction of carbon monoxide with added steam. This is done either completely, when the aim is to extract hydrogen, or to the point at which the desired hydrogen carbon monoxide ratio for the respective hydrocarbon is reached. This desired ratio is the highest for methane conversion and lower for the production of liquid fuels.

As the limitation in gasification technologies is based on the requirement to have a nitrogen-free syngas, the gasification agent is limited to a nitrogen-free component, usually oxygen or steam. As a result, the only emission beside the fuel ash ideally would be carbon dioxide. This would provide the opportunity to utilize it or reduce overall carbon dioxide emissions by carbon capture and storage (CCS) systems. Other technology limitations arise from the required size of the refinery plant at which the syngas conversion stages can technically and economically be operated.

Accordingly, when aiming for the production of transportation fuels through gasification, the applied technologies at present are oxygen-blown entrained-flow gasifiers and fluidized-bed gasifiers – either oxygen or steam blown – with the most likely conversion paths shown in Figure 11. Some typical characteristics of the gasifiers are presented in Table 6.

Due to the high technical and economical complexity of gasification-to-fuel units, the development and implementation status for commercial plants is significantly behind gasification-to-power units.

Since reliable data from actual demonstration plants are not readily available, it is impossible to provide definite information on conversion efficiencies. Several studies on the

Box 3. Examples of gasification trials and projects.

One example of a gasification-to-methane application is the demonstration plant within the Gothenburg Biomass Gasification project (GoBiGas) in Sweden, which started commissioning at the end of 2013. The plant comprises a steam-blown fluidized-bed gasifier with downstream methanation, a concept that was already successfully proven in a pilot plant at the Güssing gasifier in Austria. Several other projects are also aiming to produce methane through biomass gasification, one example being the pilot plant based on the Dutch MILENA-OLGA concept, which has also resulted in a designated demonstration plant

Although gasification to methane is currently a major area of focus, there are other concepts and projects being planned and executed. The black liquor gasification pilot plant in Piteå, formerly Chemrec and now owned and operated by Luleå University of Technology, successfully demonstrated the production of DME (dimethyl ether) in a long-term project (BioDME), funded by the EU 7th Framework Programme, in which the DME was used in trucks in actual commercial operations. The trucks have an accumulated driving distance of more than one million kilometres with DME as fuel and the pilot plant has an accumulated operational time of more than 6,000 hours. The gasifier in this pilot plant had an additional operating time of 14,000 hours when the syngas was combusted in a flare. The Bioliq pilot plant, run by Karlsruhe Institute of Technology, is another interesting example that builds on the Bioliq concept with the decentralized fast pyrolysis of biomass followed by a centralized entrained flow gasification of the resulting bio-slurry combined with downstream syngas conversion into synthetic gasoline via DME. The commissioning of the Bioliq gasifier started in early 2013 and the rest of the plant will follow suit when the gasifier is in full operation. Several other demonstration or commercial gasification plants are being planned that will produce methanol, DME or FT synthesis gas. These involve gasifier designs from companies such as ThyssenKrupp Uhde, Air Liquide, Linde and Andritz Carbona.

subject state conversion ratios between 50% and 70% from biomass to the final product, with higher numbers for gaseous fuels than for liquid fuels. It is not always clear whether these figures are gross or net based and what biomass condition they relate to.

Additionally, when aiming for an investment decision, the entire process chain has to be considered. This also includes the final use of the transport fuel as well as the efforts required to provide the necessary infrastructure for its utilization.

Recommended reading

Brown, R.C. 2011. Thermochemical processing of biomass: conversion into fuels, chemicals and power. Wiley, UK. 350 p.

Bridgwater, A.V., Czernik, S., and Diebold, J. 2008. Fast pyrolysis of biomass: A handbook. CPL Press, Newbury, UK. 196 p.

Bacovsky, D., Ludwiczek, N., Ognissanto, M. and Wörgetter, M. 2013. Status of advanced biofuels demonstration facilities in 2012. IEA Bioenergy Task 39. Vienna, Austria. 209 p.

Peralta-Yahya, P.P., Zhang, F.Z., del Cardayre, S.B. and Keasling, J.D. 2012. Microbial engineering for the production of advanced biofuels. Nature 488: 320–328.

Higman, C. and van der Burgt, M. 2008. Gasification, 2nd Edition. Elsevier. 456 p.

Knoef, H.A.M. 2012. Handbook on Biomass Gasification, Second Edition. BTG Biomass Technology Group. 500 p.

3.

From biomass to feedstock

Antti Asikainen, Rolf Björheden, Andy J. Moffat and Raffaele Spinelli

3.1 Introduction

In this chapter we discuss the organisation and operations needed to collect, transport and process forest biomass, and convert the biomass from raw material into feedstock for bioenergy. Biomass includes a range of woody materials that are uneconomic to process for alternative markets. Typical and dominating sorts are harvesting residues and small diameter wood from thinnings; in addition, subject to the current market situation for forest products, roundwood from final fellings as well as stumps and root systems can and have been utilised. Both broadleaves and conifers can supply feedstock for bioenergy. In some countries, wood from traditional coppice systems may also support bioenergy production. Processed and waste wood products (e.g. mill residues) often constitute the bulk of the woody material used for energy production.

Feedstock is a term mainly used in connection with centralised bioenergy generation in industrial plants. It implies the use of conversion processes to make forestry raw materials into products suitable for use at the energy plant. Since such plants can vary significantly in size and scale of operation across countries and regions, this can have a profound effect on how biomass is sourced and converted. Small plants (e.g. up to 5 MW) may be served locally by one or a few suppliers whereas larger plants need to be much more strategic in ensuring supply continuity.

3.2

Harvesting, chipping and transport technology

Harvesting residues

In many countries, especially in forests managed under the 'high-forest' plantation system, the greatest amount of biomass to be used for bioenergy is extracted at clearcutting. This is mainly formed from harvesting residues consisting of undersized or poorly formed trees, tree tops and branches and tree species not demanded by forest industries. Since branches with leaves or needles contain significant amounts of plant nutrients, it is common to assess the sustainability in removing these materials before this takes place. In the UK and in Sweden, for example, there is site-specific guidance in place that indicates where residue removal is permitted and where it is not. In Sweden, the redistribution of clean wood ash is a condition for the intensive removal of forest residues.

The methods for collecting residue biomass after conventional roundwood logging depends on the logging method and the degree to which the supply chain for residue removals is integrated with roundwood removals (Figure 12). For example, whole trees can be felled and skidded or forwarded to landings, where they are delimbed and

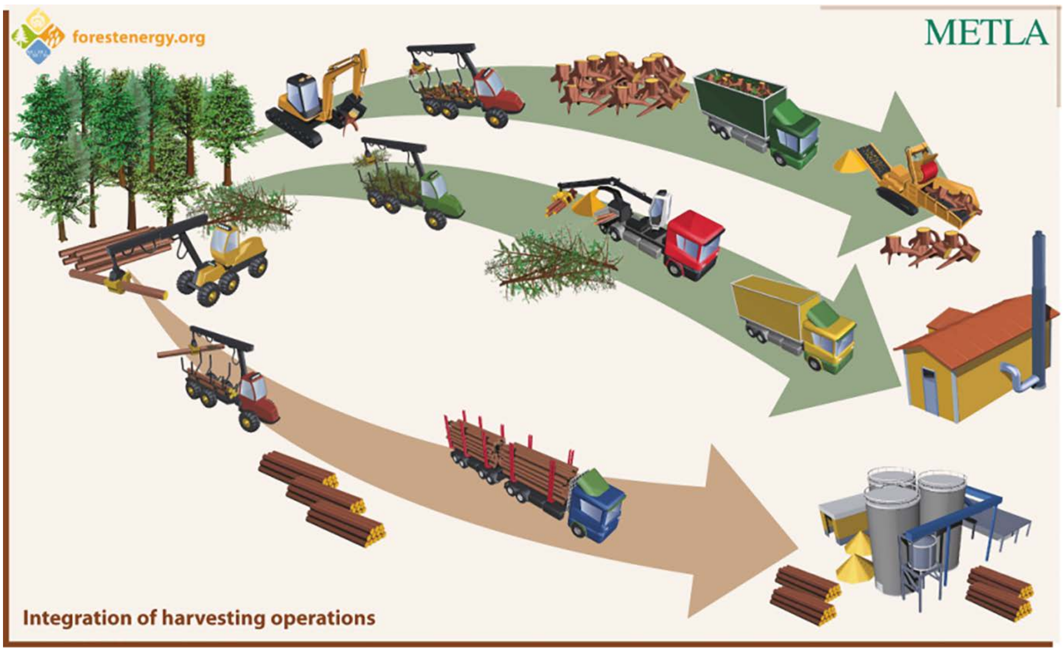

Figure 12. Supply chains for roundwood, logging residues and stumps from final fellings. Source: Forest Energy Portal.

separated into roundwood and residues; cutting can be manual or mechanised. In the Nordic countries, however, where supply-chain efficiencies for both roundwood and residue biomass is perhaps greatest, mechanised cutting is a prerequisite for the effective recovery of logging residues. Single-grip harvesters pile the residues in heaps on the logging site, the material is seasoned for a few weeks during the spring and summer months to dry and encourage the needles to fall to the ground. The residue is then loaded using a forwarder (load carrying forest tractor) or a farm tractor equipped with a grapple-loader and forest trailer and piled at a roadside landing for continued storage until transportation and processing. The piles of residues may be covered with combustible paper-based tarpaulins to reduce risks of quality loss through re-moistening due to precipitation.

Logging residues may be bundled to compact the material before being removed from the site to facilitate handling. This increases the payload during forwarding and long-distance transport, making transports less costly. However, if the residues are bundled immediately after the roundwood harvest, a major part of the nutrient rich needles are lost.

Stumps and coarse roots can also be harvested for energy after clearcutting, although concerns for detrimental soil disturbances and possible negative effects on the water quality need to be met by site-specific planning.

Excavators fitted with specially designed heads lift and sometimes split the stumps. Splitting considerably diminishes the lifting force required, soil contamination decreases and a smaller volume of soil is disturbed. Stumps are stacked in heaps on the site to dry and also to allow time and the elements to remove the soil from the stump. Soil contamination has severely weakened confidence in using stumps and roots for bioenergy in several countries; for this reason, R&D is being carried out to find means to reduce this to an acceptable level. A combination of crushing and exposure to vibration seems promising. Forwarding is carried out using forwarders with extended load space.

Whole trees

When trees are harvested entirely for energy, felling and processing becomes part of the fuel operation, unlike the collection of logging residues. Currently, the most common method used in Europe consists of felling and bunching trees using a single-grip harvester – the head is fitted with an accumulating device – that can bunch up to five trees together. Motor-manual felling, using chainsaws equipped with felling handles can also be used.

Recently, 'harwarders' – combined harvester-forwarder machines – are being tested for harvesting small trees for energy, mainly in the Nordic countries. These harwarders fell the trees and cut them into ~6 m lengths for forwarding. As the same machine forwards the material to the landing only one machine is needed to perform the whole operation. Over short forwarding distances, for small dimension wood and in small stands, harwarders are a seemingly competitive alternative to manual felling or harvesters with modified grapples.

Figure 13. Chipping at the roadside. Photo: Antti Asikainen.

Comminution

Conversion of woody biomass into feedstock is a vital step in the logistics chain of forest bioenergy production. Increasingly, methods and standards are governed by quality assurance systems such as CEN/TC335, established to develop relevant European Standards for the solid biofuels market. Individual countries may continue to use national systems. Standards help biomass suppliers and consumer to communicate unambiguously to the advantage of both.

Biomass is typically chipped into small (10–100 mm) particles to enable the efficient handling of feedstock and to improve its combustion properties. The optimal particle size distribution varies with different customers, but is generally between 30 and 60 mm for conventional grate and fluidized bed combustion units. Raw material contaminated by soil, rocks or metal, such as stumps or recycled wood, is normally comminuted by crushers and grinders. Once chipped, the material is ready to be used as a fuel by heat and power plants.

Combustion should normally take place shortly after comminution to avoid problems with mass losses and even self-ignition due to composting processes in the material.

Chipping can take place in the forest: the chipper-forwarder feeds biomass into the chipper, which is then loaded into a bin for transport to the roadside. Terrain chipping was popular in Nordic countries in the 1990s, but is now rarely used in Finland and Sweden. Terrain chippers can only operate economically on flat forest land mainly during thinnings, and were found to be too heavy and expensive for clearcutting or on coarse terrain. Because of the flexibility offered, terrain chippers are still common in Sweden since the raw materials do not have to be piled within direct crane reach of the roadside.

Most chipping is now carried out at roadside landings, but can also take place at terminals, including the end consumer, or in the wider rural environment, for example where biomass is removed from farm woodlands. Chippers can be mounted on trucks and forwarders while smaller units can be operated by a tractor (Figure 13). The optimal size of a chipper depends on the volume of operation and on the condition of the forest road network. Chippers blow chips directly into chip trucks, which then transport them to the plant. The main problem with truck mounted chippers is the interaction between chippers and trucks: the chipper cannot operate if an empty truck is not available, and the truck has to wait if the chipper has a breakdown. Also, the direct loading time of the truck depends on the productivity of the chipper. One alternative is to load the chips into containers that are brought and collected by trucks; another option is to use chipper-trucks that both chip and transport the chips, although the weight and size of the chipper means a limited truck payload and is thus less competitive over long distances.

Chipping can also be carried out at terminals located between the raw material source and the end-use facility. In this case, the raw material is first hauled to the terminal where it is stored. Chipping at the terminal can be performed by either stationary or mobile chippers. Stationary chippers are used when terminals are big (i.e. supplying over 10,000 tonnes per year). Chipper productivity is higher at terminals since the chipped material can be blown directly to the ground eliminating the need for transportation. If the terminal is located at the end-use facility, the chips can be fed directly into the fuel storage area using front-end loaders. If the terminal is located between the biomass source and end-user (or several end-users), there will be one extra hauling leg.

3.3

Logistics solutions

Transporting the biomass to the end-users in a cost efficient manner is a demanding task since forest materials have a high moisture content and low bulk density. Drying during storage reduces the water content of biomass from 50–65% for fresh conifer wood or 40–60% for most broadleaved species to 25–35% in seasoned wood. Unchipped material should be allowed to dry at the logging site because falling foliage reduces the nutrient loss from the site and also improves the fuel quality by reducing the amount of the fine fraction.

Transportation to the end-use facility can be done prior to, or after chipping. Logging residues and thinnings are mainly transported after chipping because their bulk density is very low. If the bulk density is increased by bundling or other kinds of compaction or by delimbing the stems, transport economy is improved and transportation prior to chipping becomes possible.

Transportation by rail and waterways grow in importance as the demand for bioenergy increases and distances become longer, e.g. when biomass is imported from abroad and arrives at specific ports or other entry points. This development is most likely when biomass is used in large units serving large industries and settlements, especially if it is brought to one or a few points of arrival (e.g. if imported from overseas). In Finland, for instance, the number of small heat-only units is still growing; however, in terms of biomass consumption, large CHP units, emerging biorefineries and co-generation units will play major roles. This emphasizes the need for technology and logistics solutions for multi-modal transportation and terminal operations, where biomass is transferred by other means of transport.

Because transport costs are a significant factor in determining the viability of the wood energy sector (up to 50%), GIS and modelling approaches to this challenge are becoming commonplace.

Optimization models can be used to provide the optimum solution for decisions related to the network design, technology choice, plant size and location, storage location, mix of products and raw materials, logistics options, supply areas, and material flows. In addition, sustainability considerations can be built in by including soil and geological information. Consideration of the relative amounts of CO_2 emissions can also be included in these types of decision support tools. Although global optimisation models are not easily applied on real market situations, these approaches emphasize the importance of considering the supply chain in an integrated and holistic way.

3.4

New innovations for biomass supply

Incremental innovations are frequently introduced to improve the efficiency of biomass supply. A reduction of inputs in the supply chain (e.g. fuel, investment, labour) can be obtained by enhancing the technology and logistics of biomass handling and transport, or by improving the fuel efficiency of the machinery. One way to improve the efficiency of the transportation fleet is to use the same trucks to ship a variety of goods.

A large part of biomass supply consists of loading operations: biomass is loaded and unloaded in the forest, at terminals and at the end-user's facilities. Hybrid technology improves the fuel efficiency of crane handling.

In future, the fuel efficiency of the supply chain will become increasingly important. In addition, quality management during the entire supply chain of forest fuels is required to maintain and improve the quality of feedstock and also reduce the losses of raw material before they reach the conversion plant.

Thus, the improvement of fuel efficiency, such as through hybrid solutions, payload optimization and improved quality management systems, is and will be a focal area of forest energy technology research and development.

As larger quantities of forest biomass are mobilized, more machines, vehicles and labour must be made available. There are no exact statistics for the use of forest chips for energy in the EU. Finland and Sweden use 15.1 million m^3 annually together, with the other EU countries collectively accounting for 10 million m^3. The potential of the annual harvest is about 200 million m^3 of primary forest biomass for energy. It has been estimated that the EU would need over 40,000 man years of labour to mobilize that potential (eight times more than today's labour force in forest energy supply). To meet the likely shortfall in labour, novel technologies are needed to improve efficiency. In particular, intensive automation of work tasks together with systems that guide and tutor the machine operators to run their machines efficiently will be needed. In some countries, the internet has proven a useful tool to increase knowledge and the level of training while enterprises are emerging that offer formalised training via courses and summer schools.

A significant solution to the complexity and uncertainty confronted by those interested in bioenergy generation is the emergence of agents, enterprises and businesses willing to take over the whole responsibility of sourcing materials, transporting and converting them ready for use. In addition, producer and marketing groupings are encouraged in some countries to overcome the fragmentation issue and develop economies of scale, especially in the small woods sector. These initiatives have been supported by grants and help to remove any insecurity around feedstock supply with the aim of encouraging the take-up of bioenergy.

3.5

Economy of feedstock supply

Bioenergy projects must be economically viable for all the different actors in the value chain. Woody biomass used for energy generation must compete with other uses, such as pulp and paper, and the energy produced from biomass must be competitive with that produced from traditional sources. The costs of energy feedstock and market prices of energy products are constantly changing. For example, there are large variations in the cost of fossil fuels, in particular, whilst the international supply and demand for woody biomass will also impact at a national or regional level. The viability of woody biomass markets is further affected by political attitudes to central financial control via taxation, subsidies, grants, credits, trade tariffs and other interventions which, in turn, can also change rapidly, for example with a change of government. Uncertainty in this regard has held back the development of markets for biomass feedstock in many countries.

The availability of biomass can be extremely variable between regions and countries. This poses challenges, especially if much is inaccessible or the recovery rate of biomass is low, making it financially non-viable.

For specific biomass sources such as mill residues, the cost of transportation can be minor. However, for conventional sources such as harvesting residues, which are collected over the breadth of the forest and transported longer distances, costs can be high and even prohibitive in some regions.

Efficient technologies to convert wood to energy are relatively new and still comparatively expensive. The cost differential between biomass and coal is not sufficient to generate a profit, especially when operating and maintenance costs are included. In the USA, biomass is only competitive if CO_2 emissions from fossil fuels are taxed significantly, together with the enforcement of a CO_2 emissions reduction by 20–30%. However, in some countries with a large relative forest cover (e.g. the Nordic countries), the use of primary forest biomass has become cost-competitive. This is especially so for inland energy plants where coal becomes more expensive due to longer transport distances. In Finland, the number of plants using primary forest biomass as a fuel has grown by hundreds since 2000. As the wood-based oil refining technology has developed to a commercial level, the replacement of oil in heating and more recently in transport has become economically feasible.

Factors affecting the costs of biomass supply can be grouped into two main components: (*i*) the annual availability and quality of (woody) biomass around the planned bioenergy plant (which defines the market price for the raw material); and (*ii*) costs to the users of the feedstock associated with purchase, harvesting, processing, transportation, and storage (which defines processing and mobilization costs). In areas where the use of primary forest residues is starting, the net annual increment and industrial use of wood defines the available resources. As the use of woody biomass for industry and energy increases, the competitiveness of biomass becomes an important factor affecting the availability of energy feedstock. For example, as the price of biomass decreases when the demand for pulpwood is very low, the energy industry can afford to purchase the wood for energy generation. In normal pulpwood demand situations, however, less wood is available for energy at a reasonable price.

Harvesting, chipping and transport costs of logging residues currently vary between EUR 20–25/m^3 in Eastern Europe. In Western Europe, the cost is EUR 30–35/m^3 due to higher labour and fuel costs. Production costs are especially high in mountain regions due to the difficult terrain. Unfortunately, mountain regions represent a large proportion of the forestland in many European countries, which calls for urgent technical solutions. Chips made from small-diameter whole trees add EUR 7–10/m^3 to the cost of chips made of logging residues because of felling and bunching costs. Today, the typical price paid for fuel chips in Finland and in Sweden is EUR 30–40/m^3 (EUR 15–20/MWh) and thus chips made of logging residues are cost-competitive fuels, whereas chips made of small-diameter trees need to be subsidised. In countries such as the Czech Republic and Poland, wood fuels are made competitive with coal because of subsidies supported under the EU Common Agricultural Policy (CAP).

The role of incentives is important for the promotion of the competitiveness of biomass as a feedstock. Longer lasting competitive advantage can only be reached by developing biomass production, harvesting technology and supply logistics to reduce the cost of biomass.

In addition, the product portfolio based on forest biomass must be developed towards high-value materials and fuels to enable a better ability to pay for the feedstock.

Recommended reading

Routa, J., Asikainen, A., Björheden, R., Laitila, J. and Röser, D. 2012. Forest energy procurement: state of the art in Finland and Sweden. WIREs Energy Environ. doi: 10.1002/wene.24

Spinelli R. And Magagnotti N. 2011. The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps. Forest Policy and Economics 13:520–524.

Verkerk, P.J., Anttila, P., Eggers, J., Lindner, M. and Asikainen, A. 2011. The realisable potential supply of woody biomass from forests in the European Union. Forest Ecology and Management 261(11):2007–2015.

4.

Potential in forest-based biomass production for energy

4.1 Introduction

In countries and regions with large forest resources, a developed long rotation forestry (LRF), and a forest industry, emerging bioenergy markets are initially fed with industrial residues. If the bioenergy market grows beyond that resource, there is more biomass available in the forest after logging operations such as branches, tops and stumps, small diameter trees and technically damaged wood. Market demands beyond that resource can be met by silvicultural means to increase forest growth by fertilization or improved stand establishment, among others. But it takes many decades to make a difference in LRF due to the long rotation periods.

In countries and regions with small forest resources or where the demand is higher than the sustainable supply from LRF, short rotation forestry (SRF), where fast growing tree species with short rotation periods are planted on agricultural land or other suitable land, offers an option to provide forest biomass to the market. To make a difference on the market, however, large areas are needed.

Since biomass for energy is a low priced commodity, incentives are needed both to procure existing biomass in LRF and to make SRF happen over large areas. On top of techno-economic constraints, there are also a number of environmental constraints that will limit the potential available for the market.

4.2

Potential of long rotation forestry (LRF)

Heinrich Spiecker and Johanna Schuler

Forest resources in Europe

European forests (excluding the Russian Federation) cover an area of 200 million hectares, which accounts for one third of the land area. Most of them are available for wood supply. The growing stock of currently 100 m^3 ha^{-1} is further increasing, since annual fellings are far less than the total annual wood increment of 700 million m^3. Long rotation forestry is the most common way of forest management in Europe. While the production in short rotation forestry lasts no longer than 20 years, the age of harvesting in long rotation forestry is slightly increasing and varies considerably by species and site, and coupled with tradition and management legislation in different regions it can last more than 150 years. The main products of long rotation forestry is wood used for saw timber, paper and other wood products, while only a minor yet increasing part of the residues is directly used for energy. The European Union energy target for 2020 is to cover 20% of the energy consumption by renewable energy resources. Therefore, it is expected that the use of wood for energy will increase much faster than for other uses, and that the share of other uses in total wood consumption will decrease.

Energy biomass from forests

Woody biomass directly from forests and other wooded land represents one third of the energy wood consumption. However, its real consumption by private households is often higher than the official records indicate. A substantial part of the energy wood consumption are co-products and residues from forest-based industries, including processed wood fuels with improved energy content such as wood pellets, briquettes and charcoal.

This chapter concentrates on energy biomass direct from long rotation forestry. Here, energy biomass is generally a by-product of conventional stem wood harvesting. Biomass for energy consists of smaller dimensioned timber or of lower quality wood. Small dimension wood originates from tending and early thinnings. The amount of this type of wood makes up only a very small part of the total wood production in long rotation forestry. The share of wood from later thinnings can be up to 40–50% of total wood production in long rotation forestry. It varies considerably depending on the management regimes, which are quite diverse in Europe and mainly consist of small dimensioned wood, including branches and other parts of the tree such as crowns and stem parts with defects. About half of the total biomass available from long rotation forestry consists of stem wood; one quarter of branches, needles, stem tops and bark; and a minor part of wood in stumps that are also utilized in some countries.

While small dimensioned crown wood (diameter < 7 cm), including needles ad leaves, is of no interest for conventional stem harvesting, it is a potential source of energy. Its proportion of the total wood biomass varies considerably with tree species and tree dimension. The fresh weight of small dimensioned crown wood for Norway spruce lies in a range of 60,000–75,000 kg ha^{-1} and is rather constant over age.

Potential production of energy biomass in long rotation forestry

The theoretical limit of harvestable biomass is the total amount of biomass that is growing sustainably. According to model calculations, the theoretical biomass production potential of European forests amounts to 1,300 million m^3 (with bark) per year. However, there are various constraints that do not allow this theoretical limit to be reached.

Technical constraints

Some harvesting and logging losses are technically unavoidable and remain in the forest. The losses are generally higher when the log size is small. The relative losses of needle, branch, and stem top biomass are higher than that of stem wood. The amount of losses depends on the harvesting and logging technique, the road infrastructure and logistics. The losses may increase under difficult harvesting and logging conditions and may be modified by weather conditions. Silvicultural needs, such as avoiding damage to remaining trees and regeneration in continuous cover forests, may eventually increase the amount of accepted losses.

Environmental constraints

Environmental constraints have an increasing importance for forest management. They vary with site conditions and local regulations. Sites with special ecological values – buffer zones along rivers and lakes, sites sensitive to erosion or compaction, water protection areas, areas of special biodiversity value and those with special cultural significance – require some restrictions in biomass removals. In order to support biodiversity, a certain amount of deadwood should be maintained in the forest. Areas with restricted wood supply management are, nonetheless, increasing.

Nutrient exports may lead to another environmental constraint, which may limit biomass removals in order to maintain site productivity. The amount of nutrient exports by biomass removal varies by site quality, tree species and tree age, and is influenced by the proportion of the different tree compartments.

Nutrient content increases in the following order: stem wood < branches and twigs < coarse roots < stem bark < fine roots < needles < leaves. The nutrient content of the foliage can reach up to 50% of the total tree biomass and its concentration can be more than 20 times higher in the foliage than in the stem wood. Thus, a small increase in biomass removals may result in a much larger increase in nutrient export. In general, trees on rich sites show higher nutrient contents; however, these sites are less sensitive to nutrient exports than poor sites. Due to the high amount of nutrients in foliage and twigs in some European states, some certification schemes do not permit whole tree harvesting, while others ask for biomass ash recycling in order to counteract the nutrient export. Stump logging may lead to accelerated decomposition of soil organic matter and may increase susceptibility to nutrient leaching and erosion. Increased removal of wood reduces the availability of deadwood, an indicator of forest biodiversity.

Economic constraints

As the price for energy biomass is still relatively low, it consists of poor quality wood and other tree compartments, while higher quality wood – primarily used for veneer, saw timber and other industrial products – is generally not suitable for energy use. However, the economic conditions for pulp, paper and composite products for energy wood are similar, even though the pulp industry's restrictions on the minimum top diameter may not apply for energy biomass. While the prices of energy biomass are low, procurement costs from forests are relatively high and fertilization to compensate nutrient exports may increase the costs even more. The availability of energy biomass from long rotation forestry is highly sensitive to changes in the market. Small changes in prices and procurement costs have a significant impact on the biomass potential that could be economically available from forests. There is a need to improve the efficiency of energy biomass harvesting, logging, processing and transport. Long distances from the consumer, difficult terrain and high labour costs hinder a profitable use of biomass for energy. Increasing the efficiency of biomass procurement and small, decentralized energy plant systems in close proximity to the forest will increase the amount of profitable energy biomass and at the same time increase energy security.

Social constraints

Social constrains also have an increasing impact on forest management as society demands services other than just wood production. The provision of environmental services, such as conservation of biodiversity, water quality or site productivity, are key elements of today's forest management. Laws and regulations as well as forest owners' lack of motivation may reduce the potential of providing biomass for energy. A major constraint is the willingness of the forest owner to harvest trees. An increasing number of owners are not interested in managing their forests since they generate income from other sources. As a consequence, forests become overstocked and are more susceptible to natural hazards such as storms, insect outbreaks and fungi infections.

Unpredictable changes in economic and political conditions lead to uncertainty, which may reduce the willingness to invest in energy biomass production technology. Because forest ownership is very diverse, the situation varies considerably by region.

This comprehensive list of constrains has an impact on management intensity, in particular on the harvesting and logging regime and on the provision of biomass for energy from long rotation forestry.

Potential of increasing energy biomass production in long rotation forestry

As energy biomass is a by-product of wood production in long rotation forestry, an increase of wood production will simultaneously lead to an increase in the provision of energy biomass. There are various ways to increase production and they are presented below.

(1) Increasing the productivity of European forests by increasing the forest area and by silvicultural measures such as site preparation, fertilization, weed control, protection measures, species and provenance selection, spacing, thinning intensity and production time.

Moreover, while the forest area has increased in Europe, the area available for wood supply has decreased. The prevention of production losses caused by natural hazards, such as insect attacks and storms, increases the availability of wood. In many regions in Europe, site productivity has increased during the last 60 years; however, changes in climatic conditions may eventually alter this trend. Higher initial spacing will allow early, pre-commercial thinning, but it is costly and does not contribute much to total biomass production in long rotation forestry. And while intensified thinning may provide more energy biomass in the short term, it may contribute to long-term forest resistance and resilience.

(2) As the fellings in European forests amount less than two-thirds of the increment, there is potential to increase the as yet unused proportion of annual increment.

(3) Using a higher amount of logging residues will also increase the amount of energy wood.

(4) Higher energy wood prices as well as lower procurement costs (e.g. for harvesting, logging, processing, transportation) will raise the proportion of biomass used for energy, providing the price of wood for other uses does not change. Rising energy prices and political initiatives to promote the use of wood for energy have increased the value of small timber assortments. The willingness to invest in the development of new technology in procurement and in the use of energy wood will have a stimulating effect on energy biomass consumption.

(5) As many forest owners are losing interest in wood production, mobilizing wood is a challenge for forest policy: the motivation of forest owners to manage their forests, consumer regulations, subsidies, and the willingness to invest in new technology.

(6) It is generally assumed that an increase in productivity will always result in a loss of biodiversity. It is a challenge for forest science to find ways of increasing productivity and, at the same time, increase or at least maintain biodiversity. The use of wood for energy may also be stimulated through a better understanding of global trade-offs between potential ecological losses by increasing wood removals and ecological gains by substituting products that may cause even more environmental harm.

As forest ecosystems are complex and long living, they can only be changed very slowly. However, as the demand for forest goods and services are changing rapidly, an integrative management is needed that optimizes the provision of different goods and services in an adaptive way.

Recommended reading

FOREST EUROPE, UNECE and FAO. 2011. State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. Ministerial Conference on the Protection of Forests in Europe; Forest Europe Liaison Unit Oslo. 337 p.

Burger, H. 1953. Holz, Blattmenge und Zuwachs: Fichten im gleichaltrigen Hochwald. Mitt. Schweiz. Anst. Forstl. Versuchsw. 29:38–130.

Mukkonen. P. 2007. Generalized allometric volume and biomass equations for some tree species in Europe. Eur J Forest Res. 126:157–166.

Jacobsen, C., Rademacher, P., Meesenburg, H. and Meiwes, K.J. 2003. Gehalte chemischer Elemente in Baumkompartimenten. Literaturstudie und Datensammlung. Berichte des Forschungszentrums Waldökosysteme, Reihe B, Bd. 69. 81 p.

Verkerk, H.; Lindner, M.; Anttila, P. and Asikainen, A. 2010: The realistic supply of biomass from forests. In: EUwood – Final report. Pp 56–79.

Polley, H., Hennig, P. and Schwitzgebel, F. 2004. Ergebnisse und Methoden der zweiten Bundeswaldinventur: Holzvorrat, Holzzuwachs und Holznutzung. www.bundeswaldinventur.de/media/archive/217.pdf, 15p.

Spiecker, H., Mielikäinen, K., Köhl, M. and Skovsgaard, J. (eds.) 1996. Growth Trends in European Forests: Studies from 12 Countries. EFI Research Report No. 5. Berlin: Springer-Verlag. 372 p.

4.3

Potential of short rotation forestry (SRF)

Ioannis Dimitriou and Blas Mola-Yudego

Short rotation forestry (SRF) refers to plantations with fast-growing tree species and rotations not longer than 20 years. Although traditionally used for pulp production, in the last decades a growing number of plantations has been established to produce wood biomass for energy, commonly in the form of direct combustion to produce heat and/or electricity. SRF for energy is mainly practised on agriculture land. Its management (e.g. density planted, fertilization, harvesting cycles, etc.) is less intensive than conventional agricultural crops but more intensive than conventional forestry.

One of the first countries considering the option of using SRF for energy on a commercial scale was Sweden. Already from the 1970s, research on plant biology and stand ecology of tree species from different genera (*Alnus*, *Betula*, *Populus*, *Salix*, etc.) suggested that willows grown in coppice with re-growth after harvest, were more suitable than other species for use in Nordic conditions. The establishment of commercial plantations started in the 1980s and reached some 16,000 ha by the 2000s, becoming the leader in SRF for energy in Europe. At the same time, other countries implemented similar plans to establish new willow SRF areas (e.g. the UK 8,000 ha, Poland 3,000 ha, and Germany 1,500 ha by the middle of the 2000s). Moreover, other species were trialled, depending on the climatic conditions of the areas, such as poplar (e.g. Italy, Germany, France, Spain, Sweden); hybrid aspen (e.g. Estonia); eucalyptus (e.g. Spain, Portugal, UK); robinia, (e.g. Hungary); and paulownia (e.g. Spain).

Many of these species have characteristics that favour its use for energy production: they are high-yielding, provide large amounts of lignocelluloses shortly after establishment, and have a broad genetic base. Some are easy to breed through vegetative propagation while some can have the ability of re-growth even after multiple harvests; also, low economic investments are required after their establishment. Harvesting is usually conducted every three to five years.

Today, however, the areas grown with SRF for energy in most European countries are limited, especially compared to the areas planted for pulp production, despite several predictions of rapid and drastic increases based on the potential uses of available agricultural land (e.g. set-aside or marginal lands) and the increased demand for energy wood. Indicatively, in Sweden, the Board of Agriculture predicted a short-term increase of SRF to 30,000 ha and the Swedish Farmer Association an increase up to 500,000 ha in 2020; in the UK the Biomass Strategy predicts 350,000 ha of perennial energy crops by 2020; and in Germany SRF areas may also increase significantly during next years due to subsidies and the identification of high potential for cultivation in certain areas (e.g. 200,000 ha only for the federal state of Brandenburg).

The area that will eventually be planted in the future with SRF will certainly set its potential as a source of wood biomass for energy. In this sense, it is evident that the total area planted will be the result of the adoption of the cropping system by farmers or local agents. One clear incentive for this is the profitability of the crop, which is linked to the revenues of the wood chips, the management costs and the local perception about the crop. High prices for wood chips, high yielding varieties and low costs are the ideal conditions for a farmer to grow SRF.

However, since SRF plantations are a new crop in most areas, it is necessary to convince farmers that the prices will be high enough during the next years, and growth will be reliable and not result in failure.

All these uncertainties are reduced once a market for SRF chips has been consolidated and enough experience is available. This brings us the paradox that the more area is planted, the more likely it is that more will be planted in the future, as economies of scale are reached, which reduces costs, encourages the breeding of higher yielding varieties and contributes to a better understanding of SRF management.

To study the potential and limitations of future establishment of plantations for energy, it is worth studying the development in Sweden as the pioneer in SRF systems in Europe. In the 1990s, the Swedish approach to this paradox was the implementation of policy incentives to produce a critical mass of area planted. These included at least three lines of action: funding for research schemes, subsidies for the establishment of plantations, and taxes on sulphur and CO_2 for fossil fuels in heat production. Since biofuels were exempted from these taxes, they became competitive. As a result of these changes, the planted area with willow SRF increased almost exponentially (Figure 14) in parallel to an increased demand for wood biomass by district heating plants. In the 2000s, the UK implemented a similar approach with the planted area increasing in a similar way.

The first adopters always pay the price for being a pioneer. In Sweden, the first plantations in the 1980s resulted in yields much lower than expectations (Figure 15). There were, however, radical changes in the productivity over time. At the farm scale, there was an increment due to the growers' increasing experience with the cultivation. On a general level, there were constant improvements in the average yields over time and several new varieties were released to the market, improving these initial yields in a relatively short period. This reflects a powerful advantage in the utilization of SRF versus long rotation conventional forestry: a short rotation scheme can use new and improved plant material (clones or varieties) every 15–20 years, resulting in constant improvements in the yield levels, and acting as an incentive for breeding companies once a market for the new varieties is established.

Achieving high biomass production with SRF has obviously a positive effect on revenues, which plays a decisive role for the adoption from farmers. The higher the yield and wood price, the higher the gross margins of SRF (Figure 16). Nevertheless, the development of price levels for wood chips is mostly related to local or national conditions: the energy prices of alternatives to wood biomass (e.g. hydro or fossil fuels); the price for alternative uses of wood biomass (wood prices for pulp); subsidies or other incentives for the use of wood biomass for energy; and the prices of alternatives to SRF biomass feedstock related to the market situation of the relevant industry (e.g. existence of forest residues due to forest industry situation).

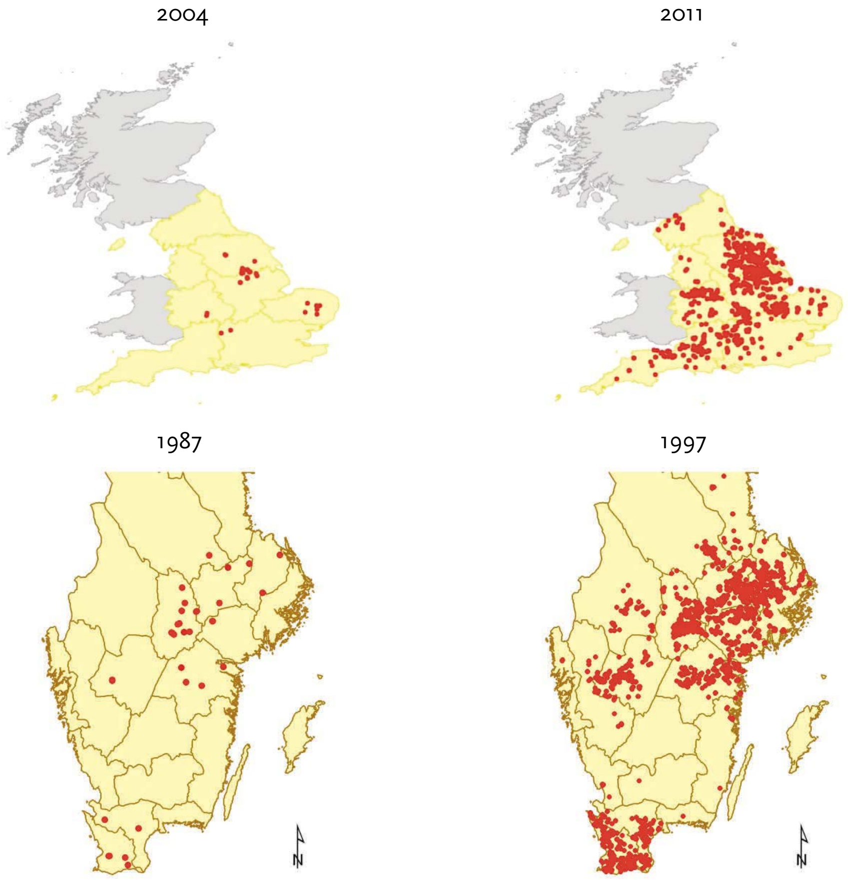

Figure 14. Spread of willow SRF plantations for bioenergy in England (UK) and Sweden, as a result of suitable policies for its promotion and adoption by farmers. The map does not include plantations under the woodland grant scheme for the UK.
Data sources: Natural England 2011, Agrobränsle, 2005 and the authors' own elaboration.

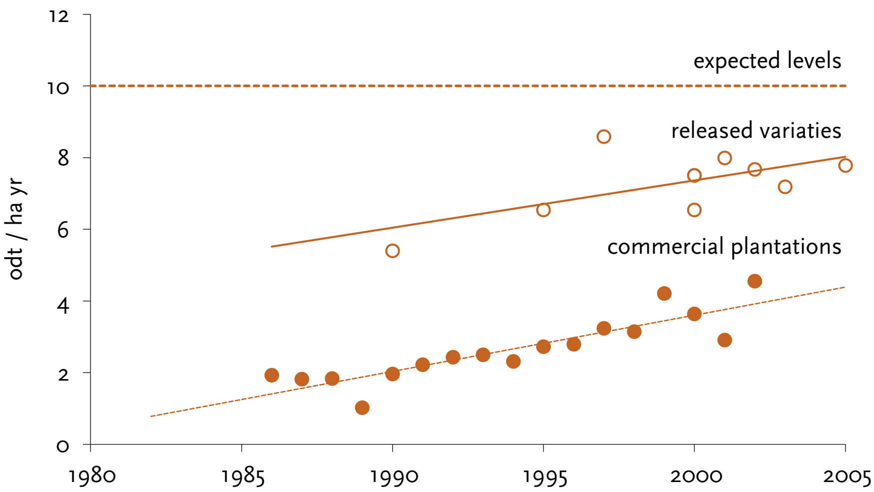

Figure 15. Expected yield levels for willow SRF plantations in Sweden, compared to the yields from trials of different clonal varieties (when they were released to the market) and to the national yield averages for commercial plantations. The yields correspond only to the first cutting cycle, as subsequent cycles are at least 50–100% higher.

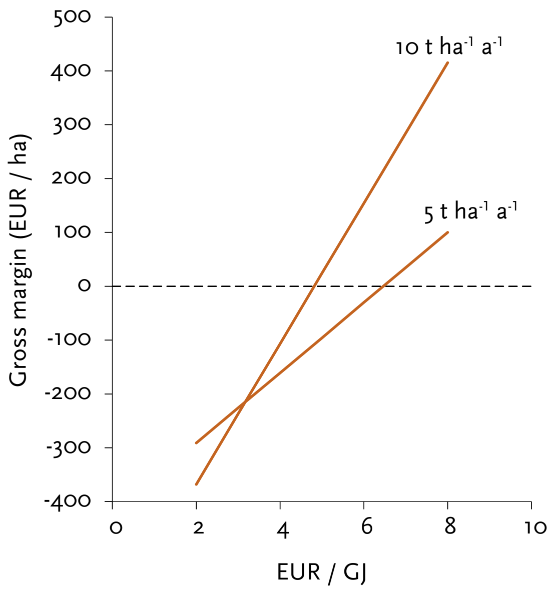

Figure 16. Annual gross margin of willow SRF plantations (EUR/ha) for a range of yields and wood chip prices (for Swedish conditions in 2009: 1 MWh = 3.6 GJ; 1 dry tonne = 15.8 GJ).

As an example, during 2005–2010, prices of willow chips in Sweden increased from EUR 5 to EUR 6/GJ at the plant, which implies a substantial increase in the gross margins of willow SRF. However, increased availability of other wood biomass (forest residues) during this period has caused fluctuation in the acceptability of willow chips for heat in power plants. It must be stressed that farmers take an important risk when deciding to plant SRF, as they cannot forecast the development of wood prices for the next 20 years. This risk has to be somehow compensated by reducing the fluctuation in prices. On the whole, and as a general trend, if biomass from SRF is an alternative to fossil fuels and will be an established market, the development of wood prices is more likely to be positive than negative for the farmers, considering the incentives for green energy adopted in most countries.

Positive externalities provided by SRF plantations must be also taken into consideration to expand planted areas, especially when they come into agreement with environmental and socio-economical goals.

Besides producing green energy and being more energy efficient in terms of energy output compared to other energy crops, there is a range of positive effects on the environment derived from SRF cultivation such as improved water quality in terms of nutrient leaching, improved soil quality in terms of increased carbon storage and decreased heavy metals, and higher phyto- and zoo-diversity when compared to traditional agricultural crops (some of these features are listed in Figure 17 where the impact of a future scenario with 20% willow SRF is illustrated, including potential negative effects). Furthermore, SRF plantations have been used to treat and utilize municipal and industrial wastewaters and municipal sludge, or for soil phytoremediation from heavy metals, producing not only biomass but also environmental services.

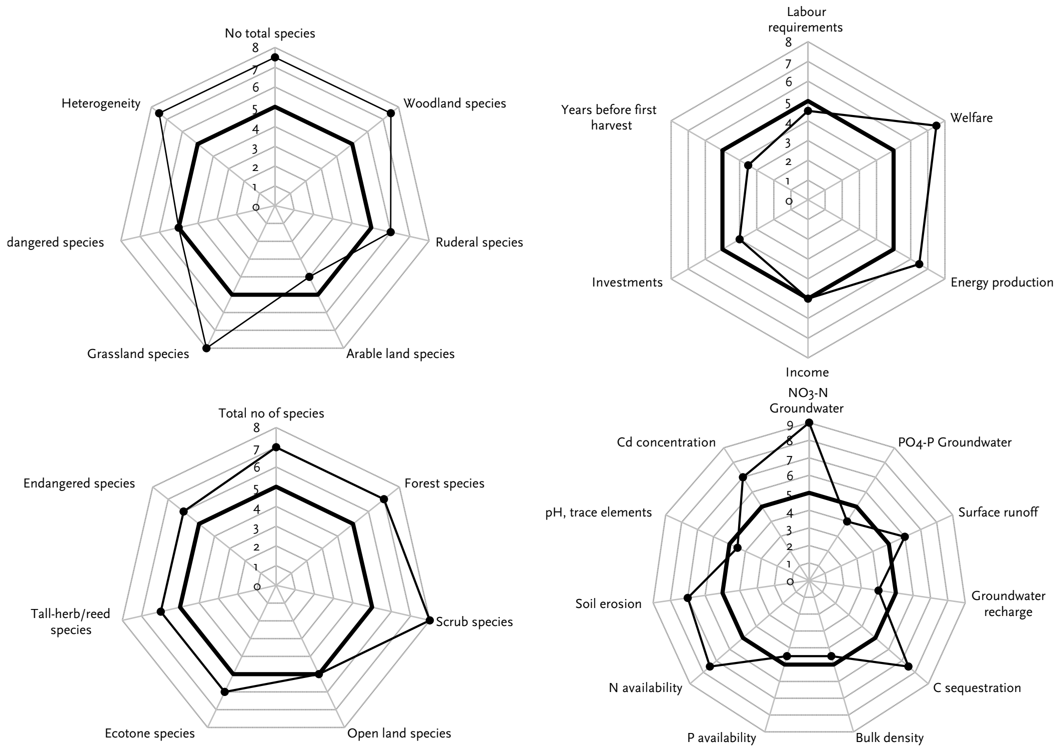

Figure 17. Impacts of willow short rotation cultivation on different environmental and socioeconomic factors. The line compares a scenario with 20% of the area planted (catchment level) to a reference level with no plantations (bold line).

To summarize, there have been several projections by decision makers on the rapid increase of SRF areas in a number of European countries. These were mostly based on future energy needs for green energy and also on European agricultural and environmental policies that in large favour the establishment SRF. However, these projections have not been realised since the majority of farmers to date have not been convinced to shift their farming to SRF. Therefore, to achieve the potential of SRF in at the regional or national level, different steps of incentives need to be taken in due time, and a holistic approach taking into account all factors interfering need to be adapted by the decision makers. Finally, we can add as key pre-requisites for the successful development of SRF: the spread of know-how based on research, skilled growers, the existence of a market infrastructure and favourable policies.

Recommended reading

Dimitriou, I. and Rosenqvist, H. 2011. Sewage sludge and wastewater fertilisation of Short Rotation Coppice (SRC) for increased bioenergy production – biological and economic potential. Biomass and Bioenergy 35:835–842.

Dimitriou, I., Rosenqvist, H. and Berndes, G. 2011. Slow expansion and low yields of willow short rotation coppice in Sweden; implications for future strategies. Biomass and Bioenergy 35:4613–4618.

Gonzalez-Garcia, S., Mola-Yudego, B., Dimitriou, I., Aronsson, P. and Murphy, R.J. 2012. Environmental assessment of energy production based on long term commercial willow plantations in Sweden. Science of the Total Environment 421:210–219.

Langeveld, H., Quist-Wessel, F., Dimitriou, I., Aronsson, P., Baum, C., Schulz, U., Bolte, A., Baum, S., Köhn, J., Weih, M., Gruss, H., Leinweber, P., Lamersdorf, N., Schmidt-Walter, P. and Berndes, G. 2012. Assessing Environmental Impacts of Short Rotation Coppice (SRC) Expansion: Model Definition and Preliminary Results. Bioenergy Research 5: 621–635.

Mola-Yudego, B. 2010. Trends and improvements of the yields from commercial willow plantations in Sweden during the period 1986–2000. Biomass & Bioenergy 35:446–453.

Mola-Yudego, B. and Aronsson, P. 2008. Yield models from commercial willow plantations in Sweden. Biomass and Bioenergy 32:829–837.

5.

Sustainability challenges

5.1 Introduction

An increased demand for biomass in European market presents large economic opportunities for several countries; however, it also raises severe sustainability challenges. Bioenergy production is usually very land intensive. Based on the National Renewable Energy Action Plans of the EU countries by 2020, the forest biomass for bioenergy needs of the EU27 would require more intensive biomass production in the existing forests or an addition of tens of millions of hectares of land area available for forestry with an intensity of the average European forest production of today. When considering land-use impacts linked to bioenergy production in Europe, it should be underlined that there can be impacts outside Europe since the quantity of wood required to satisfy the EU Renewable Energy target for 2020 is too large to be met by domestic resources and will thus require huge imports, which are already underway. The most prominent consequences mentioned by research are deforestation and forest degradation, land grabbing, and endangered food security.

These sustainability aspects connected with the development of biomass consumption in the EU are analysed in this chapter in three sections: the first presents an overall view on the main sustainability problems; the second deals specifically with the sustainability problems inside the EU; and the third section considers some issues connected with the impacts in non-EU countries on the increased European dependency on biomass imports.

5.2

Biomass production: impacts on other ecosystem services

Maria Nijnik, Bill Slee and Albert Nijnik

The impacts of woody biomass production on the multifunctionality of European forestry can be explored through the lens of ecosystem services

Forests provide multiple ecosystem services (ES) including: provisioning services of sawlogs, woody biomass for energy and non-timber forest products; supporting services, such as nutrient cycling, oxygen production and soil formation; regulating services of climate regulation, water purification and flood protection; and cultural and social services, including education, recreation and aesthetic value. Woody biomass production necessarily interacts with other forest-related ecosystem services, sometimes negatively, sometimes positively.

Woody biomass helps society to adapt to climate change by: (i) responding to an increasing demand for renewable energy sources; (ii) helping meet climate policy and EU targets on renewable/'cleaner' energy; (iii) assisting in delivering compliance with international agreements on tackling climate change; and (iv) supporting regional policies for rural employment and other development outcomes.

The original woody biomass systems of Europe comprised the use of low grade timber for burning in the form of logs and smaller cordwood. In the 'bocage' landscape in north central France and southwest England, hedgerow trees were widely pollarded for wood fuel. Coppice woodland management, which was a widespread form of pre-industrial forestry from Italy, in the south, to northwest Europe was also a major source of wood energy. In many countries, fuel wood was a secondary product where the primary product was sawlogs.

Contemporary woody biomass for energy production varies greatly across Europe, and takes three main forms: low grade wood, wood waste or wood grown for biomass (typically pelleted or chipped before burning). *Low grade wood*, often as a by-product in chip, pellet or log form, provides a significant wood energy resource in many parts of Europe. The *wood waste* 'feedstock' comprises forest industry waste, the waste arising from used pallets, packaging and wood materials, as well as residues left in the forest. *Wood grown for biomass* takes two main forms: old coppice and more recently planted biomass monocultures.

In long rotation forestry (LRF), the demands of energy markets could be met by more intensive harvesting such as through thinning, especially through the extraction of low

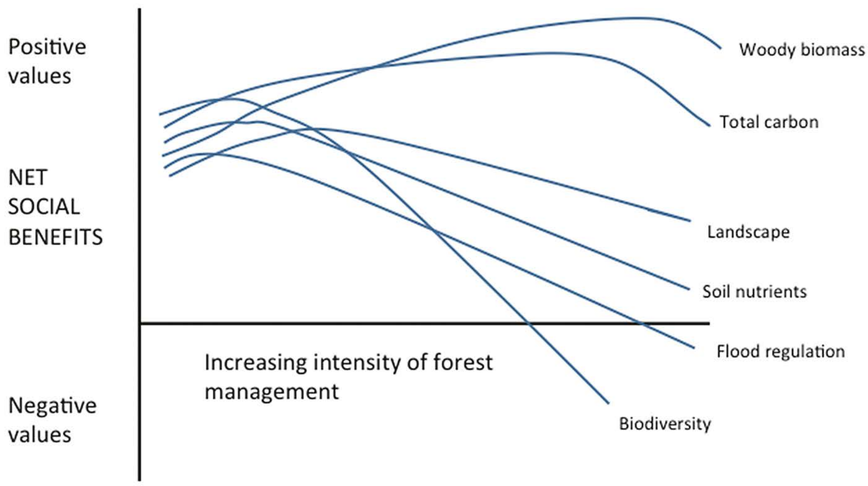

Figure 18. Management intensity and forest-related ecosystem services delivery: a generalised relationship.

grade wood and non-stem wood in the short term, and more intensive silviculture to increase future sustainable harvest levels in the mid to long term. The intensity of production will almost certainly impact on other ecosystem services (see Figure 18 for a generalised set of relationships between intensity of production and other ES).

In short rotation forestry (SRF), there is a relatively fast delivery of harvests/outputs on a production cycle of typically less than 20 years. However, such systems only cover a relatively small area in Europe (unless historic coppicing regimes are included). The main objective in SRF is the profitable production of biomass for energy. However, such systems also have an impact on ES such as habitat formation or flood protection. SRF imitates many aspects of agricultural cropping and often takes place on farms within traditional field boundaries. As such, it may positively contribute to agri-biodiversity. Traditional SRF systems, such as ancient coppice woodlands, are likely to deliver more positive ecosystem services effects than new SRF.

The relationship between biomass production for energy and other forest-related ES will be contingent on the type of wood energy used, the intensity of woodland management and the degree to which soils, biodiversity, water regulation, landscape and other ES are adversely affected. The generalised relationship in Figure 18 shows an increase in most ES as management intensity increases, up to a point, followed by a decline. In relation to a number of multifunctional services, such as landscape and biodiversity, the level of intensity at which the value of the ES declines may be quite low. It is indisputable that high intensity forest management in association with wood energy production may well diminish the value of a number of non-market ecosystem services.

The actual shape and location of the impact curves will vary from one location to another. However, the general point is that an increased intensity of production is associated with a diminution of multifunctional forest values. In practice, different elements of the multifunctional mix of forest ecosystem goods and services are influenced by markets or policies; and some ES, whilst having high public good values, may not be rewarded at all by markets or policies. Normal forest management practices and the suite of ES provided by private woodland owners cannot be expected to be close to the social optimum in view of market and policy failures, and blunt regulatory structures. Below we examine these different facets of forest multifunctionality in the context of trade-offs between ES outputs.

Multifunctional benefits arising from forestry are connected to the management and are likely to be impacted when more intensive exploitation for biomass is undertaken

The most likely scenario with greater biomass production is increased competition between different service outputs and increasing likelihood that biomass grown for energy will have to compete with other productive ('provisioning') uses of wood for pulp or timber. The management of forests for bioenergy may result in forest fragmentation and negatively impact forest biodiversity and a range of forest ES (shown in Table 7 as -), but it may also have positive effects (seen as +).

Opportunities and threats to forest ecosystem services relating to biomass production may be uncertain, and diverse in content, scale and time dimensions

The impacts on forests may be permanent; moreover, approaches to sustaining managed ecosystems may not easily allow for synergies or for balanced trade-offs between various forest functions. There may be challenges of examining thresholds and assessing 'acceptable' losses of certain species or tolerable environmental impacts. Empirical evidence is scarce and there is often a lack of reference to a specific forest service or an end-user's (future) demand for this service. There may be a lack of available knowledge with respect to the dynamics of changes, which is particularly important when exogenous drivers (e.g. climatic) and forest transition patterns (towards wood for energy production) are concerned. Not only are the biophysical impacts uncertain, the valuation methods are also contentious. Where woody biomass is imported into Europe, it may be appropriate to consider the ES impacts in the exporting country.

Woody biomass production

The production of woody biomass usually entails a trade-off between volume and quality, which is determined by the demand for different products and the cost of silvicultural interventions to enhance either volume or quality. As the wood energy market develops (with higher prices being good news from a future woody biomass production point of view), there may, however, be increasing concerns from those processing low grade wood on supply security (i.e. the particle board or pulp industries wanting to get cheap raw material).

Table 7. Examples of trade-off mechanisms: biomass production and other forest ES.

Changing conditions	Status of biodiversity	Impact on other ecosystem services
(-) Ground layer changes to more extreme humidity and temperature; soil C:N ratio changes; soil pH decreases; C and nutrient cycles change. Water flow changes.	(-) Change in the ground layer affects plant communities. Changes in biomass and C:N ratios, and C and nutrient cycles affect the decomposers.	(-) Soil fertility decreases due to the export of nutrients with residues. (-) Water flows and properties change. (-) Export of nutrients may slow down tree growth and hamper the industry, in the long-run.
(-) Residue and deadwood extraction, wood collection and stump removal may lead to a decrease of deadwood and to soil and water disturbances.	(-/+) Many fungal pathogens depend on deadwood and stumps. Their removal changes pest population and composition, and also affects their predators. Storage piles have the opposite effect. (-) Logging residues attract species laying eggs in the piles. If those are burnt before the next generation is out they have 'trap effects'. (-) Soil disturbance affect mosses and species reproducing in the vegetation. (-) Deadwood extraction leads to habitat fragmentation for dependent species. This has a much wider effect through food chains. (+) Removing stumps leads to an increase of saplings of deciduous species (this may be good for biodiversity).	(-) Soil disturbances result in soil erosion and compaction. Hydrological functions are affected. (-) Wood extraction and stump removal may result in trees damage. (-/+) Residues and stump collection affects the recreational values of the forest. (-/+) Removing stumps leads to an increase of saplings of deciduous species (this may be bad for silviculture, but good for recreation). (+) Synergies in the forest combined thinning and energy wood collection, for example, may be endorsed. (+/-) Changes in fire risk potentially affecting the ES are anticipated.
(+/-) Changes in land use.	(+/-) SRF taking place on former marginal or bare land may lead to the improvement of biodiversity status.	(+/-) If SRF replaces marginal/bare land, the ES value may increase. If natural habitats are converted to SRF or peatlands are drained this may result in water pollution, soil erosion and GHG release to the atmosphere.
(+/-) Other (wider changing conditions, including outside the site).		(+) Environmental benefits are anticipated (if fossil fuels are replaced by bioenergy). (+) The risk inherent in fuel transportation decreases (if biomass is widely produced). (+) Energy markets will likely strengthen the belief in the future wood market and increase the forest owners' will to invest in forestry activities, consequently enhancing forest other ES.

Biodiversity

There are concerns about the ecological effects of intensification in LRF and an increased removal of woody biomass, including deadwood (Table 7). This may lead to habitat fragmentation for dependent species such as beetles, flies and wasps. This affects their predators through food chains, for example woodland iconic birds like woodpeckers. Where coppicing is in place, some species (e.g. small birds) may be affected by a loss of microhabitats. With regard to SRF, much depends on the initial conditions of the land. SRF taking place on former marginal or bare land may lead to the improvement of the biodiversity status and an increase in the value of ES.

The many-sided implications regarding biodiversity are discussed in more detail in Chapter 5.3.

Landscape

The impact of more intensive production and extraction systems on the visual appearance of the landscape can be substantial. An increased scale of woody biomass production raises questions of land availability and productivity (short and long term), environmental and ecological sustainability, social and economic feasibility, ancillary effects, and species selection and mixtures (as some groups of plants and animals may have conflicting requirements). While much can be done to enhance an actively coppiced forest for wildlife through the maintenance of age and species diversity, this may conflict with maximising biomass production. More intensive, newly planted woody biomass crops may deliver fewer environmental benefits and create angular intrusions in the landscape.

Soil nutrients and protective functions

There are undoubtedly beneficial effects from leaving residues on the forest floor to protect soil from erosion on disturbed grounds where felling has occurred. Where more biomass is removed, soil nutrient status may be progressively depleted, reducing the long-term productivity of the land. Where stumps with accompanying roots are extracted for biomass, such depletion processes may be further increased. Supplementing with fertilisers or recycling wood ash is possible (yet costly); moreover, the loss of vegetative material may have structural as well as nutrient impacts on the soil. The adoption of appropriate forest management techniques (including harvesting and transporting wood) along with measures towards soil and water protection, nutrient and chemical controlling as well as biodiversity and landscape conservation can contribute to making biomass production for energy more sustainable.

Water impacts

The regulatory function of forests on hydrological systems is widely recognised. Forests are generally associated with high water quality, but potentially reduced water yield. They can also be of assistance in natural flood management. Such functions are compromised under more intensive management and extraction regimes. There are good reasons, therefore, to avoid harvesting logging residues and stumps on fine textured and/or moist soils where this is likely to increase soil compaction and erosion. Removing nutrient-rich material can reduce the amount of P and particularly N reaching the water. However, the adverse downstream effects of increased sediment and nutrient loads to waters will rarely be factored into forest biomass decision making.

Climate impacts

Climate impacts arise directly through the effects of silvicultural practices on greenhouse gas (GHG) emissions and indirectly through the distribution and use of wood raw material. A case can be made for subjecting biomass production to a life cycle analysis. Governments have frequently set ambitious targets for decarbonising their energy systems to reduce any potential impacts on the climate. This, with associated policy, has made it advantageous to exploit woody biomass to a greater degree than previously. However, different woody biomass energy systems have different ecological (and carbon) footprints. It is important to encourage those with a small footprint; but in doing so, the sustainability of the supply chain as a whole must be considered. Furthermore, it is important to ensure that fossil fuels used in extracting and transporting the woody biomass produced are factored into any analysis, and to recognise that climate mitigation benefits actually do occur. A principal benefit of increased wood fuel production is clearly the displacement of carbon emissions from non-renewable heat and electricity systems.

Since emissions reduction is a global public good, which reduces the impact of global climate change, it is not geographic specific. However, many of the multifunctional benefits and costs associated with woody biomass production for energy do have locational specificity. They affect some places and some people more than others. It is likely that an increased demand for woody biomass could even be ecologically regenerative in some countries, especially where there is a long history of small-scale privately owned forests being under-managed (as in parts of the UK).

In spite of its GHG-reducing effects when harvest levels are kept at a sustainable supply level (i.e. annual harvest ≤ annual growth), intensive extraction of woody biomass is likely to have many other adverse ecosystem service consequences. Forest practitioners throughout Europe face challenges in bringing all aspects concerning the effects of biomass production on forest ES – which are case- and context-specific – into one common framework. Targeting sustainability in operational terms is not easy. Market failures and externalities mean that where private forest practice is pursued, un-priced benefits tend to be under supplied while un-priced disbenefits rise to levels above the social optimum.

How can science help us understand the impacts of biomass production on the delivery of multifunctional forestry and the full array of ecosystem services?

First, it can help develop understanding and raise awareness of the complex effects of the use of wood for energy production. What happens to soils, water and biodiversity as production intensifies? What happens to the inherent productivity of land when more of the wood crop is removed? Can artificial or organic fertilisers be applied to remedy nutrient depletion? Does increased demand for woody biomass lead to sustainable or unsustainable intensification of production systems? How do forest owners react to an increased market for energy wood? The answers to these questions provide the building blocks of strategies for improved decision making on forest management and governance.

Second, science can endeavour to optimise the delivery of ES. This entails putting an accurate price on non-market goods and 'bads'. In the case of switching to a biomass source for energy, the cost of 'negative emissions' of any previously used non-renewable energy source needs to be factored into the equation when calculating the net societal gains. When public funds are limited, obtaining value for money will be essential. Therefore, advantage should be taken of non-market valuation methods that are becoming increasingly available and often show biomass in a broadly favourable light.

It is important, however, to realise that monetary valuation may not be necessary or feasible for estimating all the positive and negative externalities of woody biomass production. Those responsible for developing the ES approach to understanding forest multifunctionality have noted that there are some values that are not readily reduced to monetary values. Wider consultation with stakeholders may enable a consensus to be reached on optimising woody biomass use.

Third, science can help in identifying the threshold beyond which one or more ES is at stake. And when there is an issue of critical natural capital, i.e. when forest ecosystems (or their components) are nearing critical thresholds, management decisions cannot be driven by production goals or rely on economic variables. Due to the relatively slow response of ecosystems to economic variables, trade-offs between different ES (through the trade-offs in their valuation) should not be in favour of provisioning services (like woody biomass) at the expense of supporting or regulating services; moreover, the level of conservation (e.g. of intrinsic values of nature) should be price determining, not price determined.

In many parts of Europe, the technical potential for biomass production cannot be attained because of environmental and ecological factors constraining intensification. This also applies in regions where the remnants of highly valued old-growth forests of Europe are located (as in the Carpathian Mountains). In lightly wooded regions (e.g. some areas in the UK), regeneration of traditional coppicing systems may be an option. And, if done with multiple goals in mind, SRF may enhance social benefits by using land more efficiently, concurrently providing development and employment opportunities for local people at the same time as displacing the use of fossil fuels.

The key lesson from science on the impacts of woody biomass production for energy on the multifunctional ecosystem services outputs of European forestry is that we must exercise great caution in making generalisations – we must understand local social, economic and biophysical contexts and we must seek to factor the non-market goods and services more effectively into decision making through creative and effective policy design. Increasing the extraction of wood raw material from European forests will almost certainly impact other ecosystem services and must, therefore, be assessed thoroughly.

Recommended reading

Alter-Net: A Long-Term Biodiversity, Ecosystem and Awareness Research Network http://www.alter-net.info/

Daly, H. 2007. Ecological Economics and Sustainable Development: Selected Essays of Herman Daly (Advances in Ecological Economy Series). Edward Elgar Publishers.

EEA 2006. How much bioenergy can Europe produce without harming the environment? European Environment Agency Report No 7

Egnell, G. and Börjesson, P. 2012. Theoretical versus market available supply of biomass for energy from long-rotation forestry and agriculture – Swedish experiences. IEA BIOENERGY: Task 43: 2012:02 http://142.150.176.36/task43/library/otherreports/IEA_Bioenergy_Task43_TR2012-02.pdf

FAO Forestry Paper 160. 2010. Criteria and Indicators for sustainable woodfuels.

Jonsell, M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. Biomass and Bioenergy 31:726–732

Millennium Ecosystem Assessment (MEA). 2005. Millennium Ecosystem Assessment Synthesis Report http://www. millenniumassessment.org/en/index.aspx

UPM, European Biofuels Technology Platform. Brussels http://www.upm.com/en/Pages/default.aspx

5.3

Sustainability issues of using forests as a bioenergy resource

Bart Muys, Mauro Masiero and Wouter MJ Achten

Introduction

The development of a forest biomass industry offers excellent opportunities for the mobilization of the production potential of European forests and the development of a green economy. At the same time, it holds a number of risks with regard to sustainability. Potential impacts could affect European forest resources and social-ecological systems, and in the case of imported biomass, also those of third countries outside Europe (discussed in Chapter 5.4.1). In this context, the Sustainability Criteria for Liquid Biofuels already in vigour (Article 17(2) to 17(5) and Article 18(1) of the Renewable Energy Directive) and its contents are currently under debate.

In this chapter we discuss the main sustainability issues that need consideration when developing forest biomass use for bioenergy as a successful and **sustainable business**. We adopt a broad and widely accepted sustainability concept, considering the environmental, social and economic pillars of sustainability, although most of the socio-economic issues have been discussed already in Chapter 1.3. We start with the need to maintain a certain standing stock in the forest (sustained yield) and continue with the maintenance of long-term site productivity (sustainable yield) and biodiversity. We then discuss the carbon emissions and energy use associated with bioenergy production and consumption, including the risks for direct and indirect land-use change. Finally, socio-economic dimensions have been taken into consideration, including competition with other industries for material supply, sectorial governance, and implications for forest owners.

Sustained yield

European forests cover a large area (157.2 million hectares in EU27, which is about 35% of the land surface), have a large accumulated biomass stock (an estimated 24 billion m^3 of stem wood) and are characterized by low wood mobilization in many regions. Geographers describe such a context as the last stage of the forest transition to 'more people more forests'. Consequently, the transition to a bio-based economy – now boosted by the EU Renewable Energy Directive – will most likely increase pressure on the forest biomass stock, at least in parts of Europe, as it once did in populated areas before the arrival of fossil energy. A recent unpublished study by EFI shows that the execution of the National Renewable Energy Action Plans, as they are now, would inevitably lead to increasing imports of biomass from outside the EU (see Chapters 1.5 and 5.4.2 for the issues related to this effect), or to harvest rates substantially surpassing increments. A recent EFI Technical Report, however, considers that such a gap between supply and demand is unlikely to occur in the short term as there is a downward trend in the demand for forest biomass for industrial purposes. This trend also tempers energy wood consumption, as pulp mills are major producers and users of bioenergy. It is also true that a controlled increase of harvest levels closer to the increment levels would decrease the overall risk of storm and fire damage, contributing to long-term biomass stock stability.

From a historical perspective, large bio-based economies have often been a threat to forest growing stocks and areas; the sustainable bio-based economy of the 21st century must therefore demonstrate that it has the tools and methods in place to guarantee sustained yields.

Although there is undoubtedly a huge potential for biomass resources from the forest, we understand that keeping a reasonable biomass stock over time and space is, and will stay, an important management objective of sustainable forest management. Considering the current large stocks and low harvesting rates, a sustained yield is currently well ensured in the EU domestic forest sector. However, if the demand would strongly increase, what tools do we have at our disposal to maintain this sustained yield? Scientists have developed sophisticated planning and control tools but they are hardly implemented. And while many European countries or regions also have some form of legislative framework, how functional is it in ensuring this sustained yield? A stress test on the control tools in every European country is strongly recommended. At the landscape level, many forest management units (FMUs) have a management plan; but again, how operational are they in ensuring a sustained yield? Voluntary tools such as forest certification could play an important role here, but there is currently a trend towards more strict regulation at the national and European levels.

A transition to a bio-based economy in the coming decades will unavoidably make forest biomass a scarcer and more valuable resource than what it is now. Sustained yield both in and outside Europe will be at stake and yield regulation will become a policy and management challenge. A stress test on the control tools in every European country is therefore recommended.

Sustainable yield

In addition to securing the standing stock, a sustainable yield aims at maintaining the long-term productivity of the forest site. The question of whether intensive forest biomass extraction will lead to long-term productivity loss is currently under debate, especially now when stump extraction for bioenergy use is becoming common practice in Scandinavia. It has long been known that whole tree utilization exports more nutrients than stem-only exploitation. Intensive biomass extraction from forests is also known to contribute to soil acidification and leads to decreased organic carbon stocks in the long term (silvicultural measures may have a reverse influence). Extraction machinery, if not carefully used, may cause soil compaction. The detrimental effects on site productivity of repeated intensive biomass extraction from poor soils with low weathering capacity are well documented (cf. litter raking effects in central Europe). A recent Europe-wide study commissioned by the European Environment Agency shows that intensive residue harvesting and stump extraction from forests pose a serious risk for nutrient depletion, but that the risk is very site dependent.

It is good practice to extract as few nutrients from the forest as possible, and to compensate for the losses wherever needed. Limitations on stump and harvesting residues extraction are due for specific vulnerable sites.

Biodiversity

Safeguarding biodiversity is a shared responsibility of forest management Europe-wide, whatever the management purpose is.

However, there is limited knowledge on the overall effects of increased forest biomass extraction on biodiversity because its effects are multiple and site specific. In the case of biodiversity, it is not always straightforward to interpret whether the effects are to be considered beneficial or harmful; however, we can consider an intervention harmful when species richness or genetic diversity deteriorates, or when rare species requiring specialized habitats disappear. In general terms, the extraction of living or dead biomass causes a certain perturbation for the forest ecosystem's food web, which can be quantified by the 'free net primary production', it is the primary production not harvested by humans staying available for ecosystem processes. In this context, increased biomass extraction for bioenergy may be a threat to the continuous availability of standing and lying dead wood of different dimensions, both of which are key habitats for forest biodiversity.

Simple measures to maintain a sufficient share of large trees and dead wood of different dimensions in the forest landscape are effective in creating opportunities for biodiversity conservation.

If an increased biomass demand results in substantially higher price levels, this may motivate forest managers to intensify their forest management. This may lead towards the conversion of (semi-) natural forests, ancient woodlands, and other forests with high conservation value into single species plantations, the use of exotic trees, higher tree densities and shorter rotation lengths, all of which may have negative impacts on biodiversity and sustainability values.

However, increased wood mobilization may also have positive effects on biodiversity. There is accumulating evidence that the overall darkening of European forests as a result of decreased management intensity, often coupled to conversion from coppice or coppice with standards to high forest, and from mixed to single species conifer stands, has a disastrous effect on European forest biodiversity. In this context, increased wood mobilization, if characterized by more frequent and intensive thinnings and restoration of coppice systems, could meet the requirements of the intermediate disturbance hypothesis for maximizing biodiversity and have a beneficial effect on biodiversity.

While the unique heritage of (semi-) natural forests should be effectively protected from intensive biomass extraction, the biodiversity of many secondary forests might benefit from decreasing canopy density and biomass stock.

Forest use for bioenergy poses both risks and opportunities for biodiversity conservation. Increased wood mobilization from European forests needs explicit and controlled biodiversity safeguards. 'No go' zones need to be installed in virgin forests and other sensitive areas with high conservation values. However, while many Natura 2000 habitats need management and some level of biomass extraction, the conservation objectives must prevail over the harvesting purpose (LiHD or Low intensity High Diversity systems).

There is a strong perception among many interest groups in the forest sector and also increasing scientific evidence that in a context of global change, mixed forests with varying structures offer the best insurance for long-term forest productivity.

Energy and Carbon Balances

The long-term sustainability of energy provisioning systems is secured if their energy return on investment (EROI) – the ratio between harvested and invested energy – is sufficiently high. Interestingly, the EROI of first generation agro-biomass-based liquid biofuels is often only 0.8–1.6, while the actual average EROI of petrol is ±17 (but gradually declining), nuclear 5-15, wind ±18 and photovoltaics ±7. It has been calculated that an EROI of 3.5 in the late-Roman bio-economy was not sufficient to avoid collapse. An EROI of less than one means that the fuel production process consumes more energy than it yields. The EROI of wood-based bio-energy is not well documented but is generally above two (EROI of firewood-based chains even 20–40), and can be kept sufficiently high if using optimized systems in terms of harvesting and conversion technologies, and transport distances, for example. In general, EROI values of bioenergy from wood increase from second generation liquid biofuel to heat or combined heat and power systems (CHP).

The energy returns on investment of various energy systems, including wood-based bioenergy, should be thoroughly evaluated and maximized.

Probably the biggest sustainability issue of all is the greenhouse gas (GHG) balance of the wood-based bio-energy system because human-induced climate change has become the major threat to the global social-ecological system. Bioenergy systems have thus been promoted and subsidized precisely for their ability to mitigate climate change; however, this ability has been recently questioned. At first sight, the carbon balance of a forest-based bioenergy system looks pretty straightforward to calculate. Early accounting practices assumed a 100% substitution of wood energy for fossil fuels leading to large accumulating greenhouse gas savings, at least if the biomass was harvested from 'regulated forests' with a sustained yield. Recently, we are discovering that things might be less simple than they appeared: carbon balance outcomes depend very much on the actual processes used to convert forest biomass to bioenergy, on the calculation methods and assumptions.

In the framework of the EU energy policy, carbon dioxide (CO_2) tail-pipe emissions from combustion of forest biomass used for energy and transport purposes are set to zero. Biomass is thus considered as a 'carbon neutral' source, i.e. a source generating net zero carbon emissions to the atmosphere during combustion. This 'carbon neutrality' assumption is based on current UNFCCC accounting systems and assumes that the carbon (C) released while burning biomass will be recaptured by future tree regrowth; and that any excess of releases over regrowth would result in a loss of C stock and will be accounted for in the land-use sector. From this perspective, forest biomass appears as one of the most promising renewable resources for the substitution of fossil fuels and climate mitigation. The assumption is, however, based on an incomplete accounting mechanism for the land-use sector that was designed for a system where all countries account for all C stock changes from land use, whereas only few countries currently account for a limited number of C stock changes. This flaw in carbon accounting goes along with a number of additional concerns that several scientists have raised related to the carbon neutrality assumption. Most of these concerns are related to time and space issues. For example, the validity of the carbon neutrality assumption is challenged by a potential increase in harvesting levels to achieve renewable energy targets defined within national or regional policies. Such subtle land use changes release C to the atmosphere that would otherwise have been stored in the biosphere. The emission benefits of bioenergy are therefore time-dependent. While in the case of annual crops, emissions and regrowth occur within short time (e.g. one year), the carbon cycles of wood have a long time span, and a time delay exists between emissions and subsequent regrowth. This delay between emission and re-sequestration in new biomass is believed to have a temporary warming effect, which is not captured in calculations when using the carbon neutrality assumption.

Concerning these time issues, recent literature sources suggest that the assumption of carbon neutrality is not valid under policy-relevant time horizons (10 to 40 years) if carbon stock changes in the forest are not accounted for (in the Nordic countries, for instance, these policy measures took place already after the first energy crisis in the early 1970s). This is because in such short time horizons, the timing of emissions or the temporary storage of carbon in wooden products, for example, can have a relevant effect. Other voices are questioning the relevance of the timing of emissions and sequestrations on the overall long-term climate change impact.

The term 'carbon debt', which was originally introduced to highlight the large GHG emissions caused by land use change for establishment of biofuel crops (like peatland forest destruction for palm oil cultivation), is now being used in the context of biomass energy from the forest to underline that compensating for the additional emissions from bioenergy takes time. While the term 'debt' has negative connotations, it also implies that it can be 'paid off' over time, i.e. within a certain payback time that quantifies the time-lapse between C emissions and C recapture via tree re-growth. The size of the carbon debt and the length of payback time depend on several factors. Carbon debt is mostly affected by the type and amount of biomass harvested and whether land-use change emissions need to be accounted for. Payback time is mainly determined by plant growth rates, i.e. the forest biome, tree species, site productivity and management, and the energy conversion efficiency. Carbon debt and payback time are generally reported in parallel to life cycle analysis (LCA) results, where the LCA results describes the GHG emission of the biofuel production and use as such (without land use change), and where the carbon debt and repayment time are used to communicate on the size of the land-use change impact as such, avoiding to incorporate the temporal and spatial dimension in LCA (due to the complexity of LCA the interpretation would be different if more emphasis is put on consequential LCA instead of attributional LCA).

The whole carbon debt discussion probably needs some relaxation: depending on the time frame we look at, it could as well be argued that biomass harvests for bioenergy, rather than causing a carbon debt to be paid back, release a carbon credit that has been built up by forest management efforts in the past. This second thought illustrates the limitations of the carbon debt concept when using it in a context of more or less continuous land use. And similar to the chosen time window, the spatial scale of analysis influences the result. In general, C sequestration is treated differently among bioenergy LCAs as a result of different system boundaries and methods. A stricter harmonization of the evaluation tools is recommendable.

In addition to the carbon neutrality issue, correct estimation of the greenhouse gas impact of bioenergy from the forest compared to fossil energy has more challenges. The real fossil fuel substitution effect of the bioenergy supply chain depends on several factors that are currently not fully accounted for. It must be considered that the substitution is influenced, for example, by elasticities in supply-demand and price elasticities, as well as direct and indirect rebound effects.

Realistic estimations of the climate mitigation potential of bioenergy use from the forest imply explicit modelling of the carbon balance in time and space based on real world data of ecosystem carbon stock changes and product life cycles using standardized procedures.

It makes sense to require a significant greenhouse gas saving of biomass-based energy compared to fossil fuels whenever subsidies or public funds are used. The adoption of a **cascading** approach is an excellent option to improve the climate mitigation potential of the forest. Cascading means that biomass is first used for a certain material application that fits its quality characteristics best; it may be then recycled for further material or bio-refinery applications before ultimately being used for energy recuperation. Cascading use offers mitigation potential in a clear win-win with material efficiency and the creation of added value.

The forest-wood chain and the bioenergy sector have a common responsibility to actively stimulate the cascading use of wood in order to create added value with maximum greenhouse saving effects.

Other sustainability issues

One of the arguments used to question the sustainability of energy wood supply chains is the competition for wood resources with the traditional forest industry. During the last few years, the EU market for woody biomass for energy has grown faster than the wood-panel or paper markets. This is partly due to policy support and financial incentives for biomass-based renewable energy at the national and European levels. Also, the growth of connected markets, such as that of bio-liquids has stimulated the use of wood as an energy source, including the development of bio-refineries for the production of biodiesel from wood and ethanol from cellulose.

While it is obvious that increased wood mobilization for biomass energy will lead to additional job creation, the various reports available do not provide concrete evidence for the scale of those impacts. The bioenergy sector and traditional forest industry might have different performances in terms of labour intensity, with more employment and value added in the material use systems. New synergistic opportunities of industrial symbiosis may be created with bio-refineries integrated with pulp and paper plants to use the entire potential of forest raw materials and by-products, and to diversify their set of products.

When speaking about biomass for energy, sustainable wood mobilization is a key challenge. A considerable part of the available unlocked biomass stocks in Europe is located in small, privately owned forests, which makes the mobilization of these resources difficult because of ownership fragmentation, lack of appropriate infrastructures and high operational costs. While the growing demand for energy biomass represents a market opportunity for forest owners to receive income for their efforts as primary producers, concerns still exist. In general, biomass for energy has low-quality requirements, potentially drying up the motivation to apply silvicultural treatments that envisage quality timber, but which often have multiple co-benefits.

Conclusions

Forests are a valuable natural heritage, serving multiple ecosystem services for the European population. Increased use of forest biomass for bioenergy purposes touches upon a large range of sustainability issues, from ecological to socio-economic. Biomass extraction for bioenergy as with many other forestry functions has to inscribe itself in multifunctional management, and recognize that it may have trade-offs with other forest ecosystem services. In this chapter, we showed that despite its promising prospects, a growing wood for the bio-energy market may hold sustainability risks. We also showed that most of these risks can be reasonably well addressed, if the issues are well understood. This implies operating within the boundaries of sustainability and strictly respecting safeguards for biodiversity and other ecosystem services. By doing so, bio-energy sustainability can become a powerful development opportunity for the forest sector in Europe. Special attention needs to go to developing opportunities for smallholders and creating synergies rather than competing with the traditional forest industries.

Forest management in Europe has a long tradition of sustainability, which is supported by a high capacity of forest owners and managers who are institutionally anchored in agreements and regulations at the pan-European, EU and national levels, and strengthened by voluntary schemes like forest certification. Sustainability issues of biomass for bioenergy are not fundamentally different from forest use for other wood products. This would, in principle, suggest that the existing tools are sufficient and that the use of solid biomass from forests does not need specific rules. However, given the ambitious targets of the renewable energy directive, the scale and intensity could be of another magnitude, which motivates a dedicated EU initiative to guarantee forest biomass sustainability.

A subsidiarity approach is due to implement sustainable biomass use from the forest with local and national measures wherever possible, and with initiatives at the international level where needed. In general, stimulating forest owners to have a management plan or other relevant tools to be familiar with yield regulation, biodiversity conservation, and other sustainability issues is strongly recommended. The very different situation across the EU countries should be taken into account when designing new directives at the EU level in order not to increase unnecessary bureaucracy where the sustainability issues are already taken care of by existing practices or national policies.

A European directive on solid biomass from the forest would be a good opportunity to support and strengthen existing regulations and governance instruments related to forests (management plans, certification schemes, sustainability criteria, Legally Binding Agreement on Forests); however, imposing rules only valid for forest biomass for bioenergy and not for other forest or energy products would be counterproductive.

Recommended reading

Gobin, A., Campling, P., Janssen, L., Desmet, N., van Delden, H., Hurkens, J., Lavelle, P. and Berman, S. 2011. Soil organic matter management across the EU – best practices, constraints and trade-offs, Final Report for the European Commission's DG Environment.

Haberl, K., Sprinz, D., Bonazountas, M., Cocco, P., Desaubies, Y., Henze, M., Hertel, O., Johnson, R.K., Kastrup, U., Laconte, P., Lange, E., Novak, P., Paavola, J., Reenberg, A., van den Hove, S., Vermeire, T., Wadhams, P. and Searchinger, T. 2012. Correcting a fundamental error in greenhouse gas accounting related to bioenergy. Energy Policy 45:18–23.

Jonker, J.G.G., Junginger, H.M. and Faaij, A. 2013. Carbon payback period and carbon offset parity point of wood pellet production in the Southeastern USA. GCB Bioenergy. doi: 10.1111/gcbb.12056

Mantau, U. et al. 2010. EUwood – Real potential for changes in growth and use of EU forests. Final report. Hamburg/Germany, June 2010. 160 p. http://ec.europa.eu/energy/renewables/studies/doc/bioenergy/euwood_final_report.pdf

Messier, C., Puettmann, K.J. and Coates, K.D., 2013. Managing Forests as Complex Adaptive Systems. Building Resilience to the Challenge of Global Change. Earthscan from Routledge. 368 p.

Muys, B., Hetemäki, L. and Palahí, M. 2013. Sustainable wood mobilization for EU renewable energy targets. Biofuels, Bioprod. Bioref. 7:359–360.

Röser, D., Asikainen, A., Raulund-Rasmussen, K. and Stupak, I. (eds.) 2008. Sustainable use of forest biomass for energy. Managing Forest Ecosystems, 12. Springer, Dordrecht.

Solberg, B, Hetemäki, L., Kallio, A.M.I., Moiseyev, A. and Sjølie, H.K. 2014. Impacts of forest bioenergy and policies on the forest sector markets in Europe – what do we know? EFI Technical Report 89.

5.4

Sustainability at Source

5.4.1 Responsibilities beyond domestic forests

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When considering land-use impacts linked to bioenergy production in Europe, it should be underlined that impacts can also take place outside Europe since the quantity of wood required to satisfy the EU Renewable Energy target for 2020 is too large to be met by domestic resources alone and will require huge imports which are already underway. The probable consequences cited in research are deforestation and forest degradation, land grabbing and endangered food security, among others.

While it is not clear to what extent the additional quantity of required bioenergy will be sourced from outside the EU borders, the EC stated that the bulk of this bioenergy will be in the form of wood pellets from forest-based industries, increasingly coming from outside the EU. Currently, the USA and Canada are the main pellet exporters to the EU. The growing demand for pellets in Europe has led to a fast growth in wood pellet manufacturing facilities across southern USA that have been sourcing wood mainly from fairly short rotation (35 years) pine plantations as well as from high biodiversity value wetland forests. Several USA based NGOs and scientists have raised concerns against the EU renewable energy policy, stating that the current sustainability rules are inadequate and that this policy poses a serious threat to forests outside the EU. European markets are currently searching for more non-traditional suppliers in the global south. For example, experts indicate Brazil as one of the most promising future partners for Europe as a source of wood pellets, thanks to its good infrastructure and relative proximity.

While deforestation and forest degradation represent direct land-use changes (dLUC) linked to woody biomass production, indirect land-use changes (iLUC) should also be taken into consideration. As for direct land-use changes, the most evident is the conversion of (semi-) natural forests into plantations, which has taken place on a large scale for the production of oilseed crops and for timber or pulp production. Until now, wood energy production has been mainly based on residues from the forest; however, forest conversion to short rotation coppice for bioenergy purposes might emerge in the future. Indirect land-use change refers to the displacement of a current by a new land use (e.g. biofuels), which results in a land-use change somewhere else, referred to as 'leakage'.

Societal discussions are linking research to politics in many ways. These discussions raise hot topics, which may have a strongly polarizing influence in the society, even though the likelihood of rather theoretical issues that may be realized are small. For example, if the development of a short rotation coppice plantation results in the displacement of farmland, and if the farmer makes up for the shortfall in agricultural production by bringing previously uncultivated land into production, this latter land-use change would be considered as an indirect land-use change effect of the short rotation coppice plantation and its products. The related consequences in terms of CO_2 emissions, or decreased prosperity or increased competition with food, local energy supply, and other materials could therefore be burdened to the energy produced from the plantation.

At present, iLUC is not properly addressed by the proposed biomass criteria developed by the EC in 2013. Article 17 of the Renewable Energy Directive prohibits the conversion of natural ecosystems for biofuel production; however, no similar restrictions limit the conversion of natural ecosystems to agricultural production that may result from iLUC from increased biofuels production. One problem is that iLUC is an ill-defined concept based on immature methodologies with a high risk of double counting that would become superfluous if direct land-use change could be fully accounted for.

There is a risk that part of the land occupation worldwide caused by current and future European wood fuel needs will be considered land grabbing practices. According to the Tirana Declaration by the International Land Coalition (2013), land grabbing occurs in the case of acquisitions or concessions in violation of human rights, not based on free prior and informed consent of the affected land users, in disregard of social, economic and environmental impacts, not based on transparent contracts specifying commitments about employment and benefits sharing, or not based on effective democratic planning and participation. It provokes increased competition for land that could, in turn, increase social tensions and cause conflicts, especially in areas that are already characterized by food insecurity and vulnerable land rights (e.g. South-East Asia and Africa).

Food security can be threatened by energy wood production for export to the EU in different ways. First of all in terms of direct competition between biomass plantations and food crops for fertile lands with high yields, good infrastructure and market accessibility. When bioenergy plantations displace food crops, it may generate competition for land between international concerns and local communities such as marginalizing smallholder farming. If biomass production is export-oriented, then local energy security may also be negatively affected. Land-use conversion of 'marginal lands' to biomass plantations often represents an opportunity cost for local communities in terms of grazing, collecting firewood or gathering/selling non-timber forest products, as well as a loss of local traditions and cultural identity. On the other hand, biomass plantations and food crops do not necessarily exclude each other. They can co-exist and even strengthen each other in highly resilient agroforestry systems.

Europe's renewable energy policies have a responsibility that reaches wider than domestic forests, and that should develop effective regulations and follow-up to avoid negative impacts on social-ecological systems worldwide, including deforestation, forest degradation, land grabbing and food insecurity.

5.4.2 Cross-continental challenges

Promode Kant, Anatoly Shvidenko, Warwick Manfrinato, Luiz Fernando de Moura and Petro Lakyda

Access to large attractive markets has obvious economic advantages, but it also has the potential to severely erode the fundamental strengths of the exporting economy by permanently depleting its natural capital stock and, thereby, its capacity to pursue its own good in perpetuity. Sustainable development of a society requires continuous and increasing access to physical and biological natural capital besides human, technological and financial capital across generations. Biological natural capital, including forests and other productive lands, remains renewable only if it is not depleted below a critical threshold. High profits in a rich market for products grown in countries with poor governance can quickly lead to renewable resource depletion below this threshold. This is a major risk in large-scale biomass production for export to the EU in many African countries and, to a lesser extent, in Latin America.

Here, we concentrate on some countries in Europe (Russia and Ukraine) and in Latin America and Africa. As presented in Chapter 1.5, due to the huge energy demand of India and China, Asia may not be important biomass suppliers for the EU in the future and are not discussed here. North-America has been discussed in Chapter 1.5.

A more immediate concern, under conditions of poor governance and tolerance of inequity in a hierarchical society, is of land grab. With land property rights in many countries of Africa and Latin America in an indeterminate state, the acquisition of large extents of rural lands by biomass producing enterprises runs the risk of displacing people from their existing enjoyment of lands, particularly when it is not legally recognized. Increased competition with food crops for both land and water can also induce considerable stress in rural societies in poor countries. Moreover, there are risks of clearing lands of existing vegetation and harm to biodiversity for raising commercial plantations of a few preferred species for maximizing biomass production which could also lead to severe loss of soil nutrients. Increased demand for biomass would also raise pressure on domestic supplies resulting in an unbearable rise in wood energy prices for the local poor.

The move to renewable forms of energy, including bioenergy, is primarily motivated by the overwhelming need to mitigate climate change by reducing greenhouse gas emissions. But since the production and transport chains are long, and often disjointed and invisible at several points, the true extent of emission reductions over the complete life cycle is often in doubt. Many recent studies of bio-ethanol production as transport fuel in the US have shown that life-cycle emission reductions were often a minor fraction of what was claimed.

Addressing these risks to the social, economic, ecological and environmental sustainability of biomass production is not beyond the available financial and technological capabilities of the EU and the concerned countries, but it would require thorough risk assessment and very determined and planned interventions. The measures taken must also be compatible with the provisions of the WTO, whose member countries are not permitted to discriminate between 'like' products produced in other WTO member countries or place non-tariff barriers on imports and exports within the WTO fraternity.

However, limited and clearly defined restrictions for protecting human, animal and plant life or health, and for conservation of exhaustible natural resources, may be justifiable when they are also taken along with similar restrictions on domestic production and consumption. A recent study by the Oxford Global Canopy Programme recommends enacting policies for public procurement of forest commodities; entering into bilateral and multilateral agreements with major exporting countries to restrict trade to sustainably produced forest goods; and the use of import tariffs and other trade measures for discouraging consumption of unsustainably produced forest commodities in EU.

The same study also recommends that since WTO rules do not restrict private enterprises from full control over their own supply chains, an effective strategy would be for WTO member countries, as part of their domestic actions, to encourage them to produce and consume increasingly more sustainable forest commodities. National governments could also work with the industry organisations to reduce the costs of producing sustainable forest commodities, develop best practices, support certification initiatives and enhance access to cheaper loans for these measures. It is important that sustainability is defined in a non-discriminatory framework by criteria, rather than by membership of a preferred certification standard.

Forest Law Enforcement, Governance and Trade (FLEGT) is a good example of a reasonably effective framework for establishing voluntary partnership agreements between the EU and countries exporting forest commodities aimed at discouraging illegal felling and unsustainable forestry practices. It is an EU programme initiated under the UN Non-legally binding Instrument on All Types of Forests for strengthening political commitment and action towards the sustainable management of all types of forests to achieve the shared global objectives on forests. Millions of hectares of forests around the world continue to be degraded due to excessive and illegal removals for trade. Access to premium markets, such as in Europe, further exacerbates the problem as the higher profit margins make illegal harvesting even more attractive. Agreements under FLEGT seek to strengthen the institutional capacity of partner countries to minimise the negative impacts of unsustainable forest harvesting on local the environment, economy and society.

Since Russia is potentially the biggest source of biomass for energy, the widespread problem of illegal logging there is a prime cause of concern for the EU. According to official data of the Russian Federal Agency of Forest Management, illegal logging equals 1.2-1.8 million m^3 annually or about 1% of the total harvest; unofficial estimates, however, place the average illegal harvest in major forest regions at about 20–25% of the officially reported amount of harvested wood and even more in the export-oriented forest regions, particularly along the border with China where unscrupulous trade practices predominate. A more dangerous and predatory form of illegal felling is the selective excess removal of valuable endemic species, often on protected areas. An example of such ecologically damaging harvest is the reported export to China of 0.9 million m^3 of Mongolian oak in 2010, when the annual legally permitted harvest is barely half this quantity in the Primorsky and Khabarovsky forests, which are the only places in Russia where this species grows. However, this kind of extreme forestry processes can seldom be linked directly with the development of the bioenergy market.

However, authorities at the federal and regional levels in Russia have realized the various problems of ecologically damaging harvesting and illegal logging, and have made some efforts to combat this problem. The Russian Federation has adopted the Plan for the Prevention of Illegal Logging and Illegal Wood Trade; moreover, a special Commission and working group for the prevention of illegal logging and the illegal wood trade have been established, and airspace monitoring of forest harvesting now covers more than 100 million ha annually. The situation, however, remains serious in many settlements where the forest is a major source of subsistence for a number of reasons, including difficult social situations. Much work remains to be done in the Russian Far East to combat 'illegal logging', for which an exact and acceptable definition does not yet exist in Russia. In these forestry circumstances, sustainability targets should be defined before more intensive forest biomass harvests is introduced.

Forest certification has made some progress in Russia. By the end of 2011, 30 million ha of Russian forests had been certified under the Forest Stewardship Council (FSC) scheme and about 0.2 million ha under the Program for the Endorsement of Forest Certification (PEFC) placing Russia second in the world after Canada in terms of certified forest areas. Although the biggest Russian exporters of wood products are certified, certified forests comprise only 26% of all forests leased for logging, with a major part (63%) situated in European Russia.

Unlike Russia, it is not illegal harvesting in Ukraine that has posed a problem to the sustainability of forestry practices; rather, it is inadequately planned harvesting that leads to the excessive removal of mature trees in accessible forests rendering them full of young stands. Some remedial steps, however, have been initiated: for instance, forest certification has picked up considerably with 1.63 million ha of its productive forests now under FSC certification.

Despite severe challenges, there has been distinct progress in the sustainable management of forest resources in Brazil. It would not be very difficult, therefore, for the EU to find ways of doing business with Brazilian exporters by working with the Brazilian government and other organizations including private businesses. Elsewhere in Latin America, Honduras and Guyana are presently negotiating a FLEGT Voluntary Partnership Agreement with the European Union. To this end, exploratory missions have been carried out to Bolivia, Colombia, Ecuador, Guatemala and Peru. Even though realization of a Voluntary Partnership Agreement would improve the sustainability of forestry, it is unlikely that these smaller countries of Latin America would play any important role in the future bioenergy market in Europe. Today, the EU Timber Regulation (Regulation (EU) No. 990/2010) is an even more important policy instrument than the Voluntary Partnership Agreements (still limited to a few countries). Under the regulation, operators introducing biomass in the EU internal market for the first time must have a system of Due Diligence in place to prevent the introduction of illegal wood.

Africa presents the biggest challenge. In Africa, the first priority should be to ensure fuel wood supply for local consumption is not affected by biomass exports. After this has been taken into account, the EU needs to devise sustainable ways of providing access to its biomass market to ensure that the rural people in Africa benefit from increased incomes and employment and yet, given the pervading environment of corruption ridden and poor governance in many African countries, the EU also has the responsibility of ensuring that the business and governance intermediaries are not permitted to grab lands from the poor and destroy the wealth of the natural forests and biodiversity in these countries. The EU has already initiated FLEGT process in several African countries where it is in the advanced Phase 3 of systems development in Cameroon, Republic of Congo, the Central African Republic, Ghana and Liberia; and in Phase 2 of formal negotiations in Democratic Republic of Congo, Gabon and the Republic of Côte d'Ivoire.

Summary

The enormously increased demand for biomass in the European market presents large economic opportunities for several countries, but it also raises severe challenges of sustainability. Russia, with its vast forest resources and physical proximity, is the biggest potential source of biomass also as syngas after blending with natural gas and supply through the existing gas pipeline network. Belarus also has good potential for export to EU with careful monitoring against radiation exposure. Pellet supplies from North America are environmentally compatible with EU sustainability requirements, but would likely diminish over the coming decades as domestic needs grow. Improving social and environmental sustainability of sourcing biomass from Brazil would be necessary before its natural advantages as a biomass producer could bring large benefits to all stakeholders. Africa should benefit from increased demand for the biomass it can produce at low costs, but social sustainability of large scale production will remain a central challenge. Measures taken by the EU to ensure sustainability should be compatible with WTO provisions.

Recommended reading

AEBIOM (European Biomass Association) 2012. Europe: Bioenergy Outlook 2012, Statistical Report.

European Commission. 2010. 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

FAO UN. 2012. The Russian Federation Forest Sector Outlook, Food and Agriculture Organization of the United Nations, Rome. 84 p.

Gerasimov, Y. and T. Karjalainen, 2010. Atlas of the forest sector in Belarus, Working Papers Working Paper 170 of the Finnish Forest Research Institute

Grätz, J. 2012. Russia's Pipeline Overstretch: Market Monopolisation at the Expense of Reliability, Russian Analytical Digest, No. 113, May 15, 2012.

Hewitt, J. 2011. Flows of biomass to and from the EU – an analysis of data and trends".

IEA 2008. Non-OECD country statistics. International Energy Agency, Vienna

IEA 2012. Technology Roadmap, Bioenergy for Heat and Power, Vienna

Leggett, M. 2013. Drivers of deforestation and WTO rules: Conflicts and Solutions. Oxford: Global Canopy Programme.

REA. 2011. Development of biofuel market in the world and in the Russian Federation. Russian Energy Agency, Moscow, 56 p. [in Russian].

REA. 2012. Bioenergetics in Russia in XXI century. Russian Energy Agency. Moscow, 37 p. [in Russian].

Sheingauz A.S. 2008. Selected Works. Far Eastern Branch of the Russian Academy of Sciences, Khabarovsk, 654 p. [in Russian].

Shvidenko A., Schepaschenko D. and McCallum I. 2010. Bottom-up Inventory of the Carbon Fluxes in Northern Eurasia for Comparison with GOSAT Level 4 Products. Report. International Institute for Applied Systems Analysis, Laxenburg, Austria, 210 p.

WWW. 2013. worldwildlife.org/threats/deforestation

6.

Conclusions

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Forest bioenergy: a thousand different things

Forest biomass production helps society to respond to an increasing demand for renewable energy sources, meet EU climate policy and renewable energy targets, and comply with international agreements on tackling climate change. It also supports regional policies in enhancing the rural economy and employment opportunities.

Forest biomass-based bioenergy can be a thousand different things. The forest biomass source and its management, the end products (heat, power, transport fuel), the conversion technology, the logistics, the environmental impacts, and the markets and opportunities to use bioenergy may vary significantly across the EU and across regions within countries. As a result, one size fits all policies are not optimal for enhancing forest biomass-based bioenergy development in a sustainable way. New policies are needed. Markets do not take care of the externalities (including public good s and bads), and there are already policy failures and a lack of policy coordination, distorting market incentives. Renewed assessments and policies, and better policy coordination are needed.

Policy recommendations

Reassess EU forest biomass demand

Recent studies (Mantau et al ., 2010) have suggested that the EU's forest biomass supply would increase by 11% from 2010 to 2030. However, assuming the EU's 2020 climate and energy targets, and the continuation of forest products markets along past trends, this study also estimated that the demand for forest biomass would increase by 73%. This would mean a shortage or a "gap" of 316 million m^3 of forest biomass in 2030. This "gap" has aroused concerns that scarcity of wood could lead to fierce competition over woody biomass, and that there could also be a significant loss of forest biodiversity due to increasing forest biomass usage.

However, there are three main factors not included in the EUwood study:

1. The ongoing structural changes in global and EU forest products markets are likely to result in a lower demand for and production of forest products in the EU. The forest biomass demand for industrial purposes is therefore likely to be lower.

2. The EUwood study does not consider the impacts of international trade in forest biomass. Imports already exist, and are likely to increase in future, given that markets and policies in the EU provide incentives for this.
3. Forest biomass, forest products and bioenergy production react to market incentives such as the prices of raw material and end products. These market adjustments may be significant and help to clear the "gaps" between supply and demand for forest biomass.

These factors suggest that the future usage of forest biomass in the EU may not be as large as is often thought. We need to reassess future EU forest biomass demand to also take into account these factors. New EU climate and renewable energy targets and policies for 2030, to be decided in 2014, will increase the need for reassessment.

Address the hidden impacts of policies and trade-offs

Given the uncertainty of future carbon and energy prices, renewable energy sources (RES) policies help to promote new investments. However, they can also cause new problems. Subsidies directed to one sector may harm other sectors, and can also increase the costs of mitigating climate change. For example, research has found that if subsidies are given for biodiesel production, this tends to increase the forest biomass price, which in turn may decrease the production of wood-based heat and power. In some cases, it could also decrease pulp and panel production.

Policy makers need to be better informed about the many impacts that policies may have. They need to have clear priorities guiding them to accept trade-offs between sometimes conflicting policy goals.

Tailor sustainability policies

Environmental, economic and social sustainability is a key condition for successful business development in the forest biomass sector. But securing these objectives is a challenge for policy makers. For instance, if a RES policy triggers woody biomass imports to the EU, these should meet the same sustainability standards as forest biomass from within the EU. The EU Timber Regulation ensures the legality of wood placed on the EU market, but this does not guarantee all dimensions of sustainability.

Another important issue is the carbon neutrality of forest biomass as fuel. Because of the many different ways that bioenergy can be produced, the energy efficiencies and climate (carbon) impacts of forest biomass-based energy production may vary greatly. Consequently, RES policies can have different sustainability impacts. We need further studies to synthesise the best scientific knowledge about carbon neutrality, and point out the interlinkages between bioenergy and climate policies, and the implications for policy. There are no silver bullets. Simple solutions and widely applicable generalizations are not easily found for sustainability questions.

Focus on energy efficiency, minimizing emissions and promoting new businesses

The potential annual harvest of biomass from forests for energy in the EU is about 200 million m^3. There is also still plenty of potential and need to strengthen the utilization of industrial wood residues (e.g. sawdust and chips) and post consumer wood (e.g. packaging materials, demolition wood, timber from building sites). It is estimated that the EU would need around 40,000 person-years in labour input to mobilize the full potential of harvested forest biomass for energy - eight-times the number who work in forest energy supply today. To meet this likely shortfall in labour, novel technologies are needed to improve efficiency in energy biomass harvesting, logging, processing and transport.

Long lasting competitive advantages can only be reached by developing biomass production, harvesting technology and supply logistics to reduce the cost of biomass. It is also essential to improve the energy efficiency of the production processes. The product portfolio based on forest biomass must be developed towards high value materials and fuels to enable a higher ability to pay for the feedstock. But to operate these more efficient technologies and processes, we need agents, enterprises and businesses willing to take over responsibility for sourcing materials, transporting and converting them ready for use, and producing the products.

Policies which create incentives to help facilitate economic, technological and environmental efficiency developments and business opportunities for the whole forest biomass-based energy supply chain are needed. Policies should direct support to the most energy efficient and least emission-generating production processes.

Design a stress test for sustainability

Forest biomass-based bioenergy production may result in significant environmental and economic sustainability gains for the EU. However, this is not guaranteed, and will not happen automatically. The market mechanism by itself will not guarantee that all environmental and economic objectives are met. Energy from forest biomass is not a single entity, but hides a large variety of sources and qualities, conversion technologies, end products and markets. Some processes do make economic and environmental sense, others not. Therefore, bioenergy-related policies should be designed in a way that enhances technological and economic efficiency, and environmental sustainability.

A stress test needs to be designed and implemented to guarantee that forest biomass-based bioenergy production supported by subsidies or other policy means in the EU has an environmentally and economically sustainable basis. The stress test would determine the ability of a given forest biomass-based bioenergy process to guarantee certain environmental and economic sustainability criteria. For example, the following stresses could be analyzed:

- What is the carbon balance of the process?
- What are the biodiversity impacts of the process?
- What are the potential trade-offs (opportunity costs) in terms of forgone alternative forest uses?
- What is the energy efficiency of the process?
- What is the socio-economic viability of the process (to what extent it needs policy support, and for how long?)

Recommended reading

Mantau, U., Saal, U., Prins, K., Steierer, F., Lindner, M., Verkerk, H., Eggers, J., Leek, N., Oldenburg, J., Asikainen, A. and Anttila, P. 2010. EUwood – Real potential for changes in growth and use of EU forests. Final report. Hamburg/Germany, June 2010. 160 p

List of abbreviations

AEBIOM European Biomass Association

BIGCC biomass integrated gasification combined cycles

CAP Common Agricultural Policy

CCS carbon capture and storage

CGE cold gas efficiency

CHP combined heat and power

dLUC direct land-use changes

DME dimethyl ether

EAFRD Agricultural Fund for Rural Development

EROI energy return on investment

ES ecosystem service

EU ETS European Union's emissions trading scheme

Eurostat The Statistical Office of the European Communities

EUTR EU Timber Regulation

RES renewable energy sources

FLEGT Forest Law Enforcement Governance and Trade

FMU forest management unit

FSC Forest Stewardship Council

FT Fischer-Tropsch

GHG greenhouse gases

GIS geographic information system

HDO bio-oil hydrodeoxygenation

IEA International Energy Agency

iLUC indirect land-use changes

INC Intergovernmental Negotiating Committee

JWEE Joint Wood Energy Enquiry

LBA legally binding agreement

LCA life cycle analysis

LiHD low intensity high diversity

LRF long rotation forestry

LZCT low and zero carbon technologies

ORC organic ranking cycles

PEFC Program for the Endorsement of Forest Certification

REA Russian Energy Agency

SRF short rotation forestry

UNECE United Nations Economic Commission for Europe

UNFCCC United Nations Framework Convention on Climate Change

VPA voluntary partnership agreement

VTT Technical Research Centre of Finland

kW kilowatt (10^3 watt)

EJ exajoule (10^{18} J)

€/GJ euro/gigajoule (€/10^9 J)

GWh gigawatt hour (10^9 Wh)

Mt megaton (10^6 t)

MW megawatt (10^6 watt)

TWh terawatt hour (10^{12} Wh)

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