Lappeenranta University of Technology

Jussi Heinimö

DEVELOPING MARKETS OF ENERGY BIOMASS – LOCAL AND GLOBAL PERSPECTIVES

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium in MUC, Mikkeli University Consortium, Mikkeli, Finland on the 15th of December 2011, at noon.

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The research included in this thesis was carried out in two universities – at the Institute of Energy Technology of Lappeenranta University of Technology, Finland, and partly at the Copernicus Institute of Utrecht University, in the Netherlands. IEA Bioenergy Task 40 (‘Sustainable International Bioenergy Trade: Securing supply and demand’) and research projects entitled ‘International bioenergy trade: Business opportunities and forecasting the effects for Finland’ and ‘Global forest energy resources, sustainable biomass supply and markets for bioenergy technology’, funded by the Finnish Funding Agency for Technology and Innovation (Tekes), have offered the framework for the realisation of this thesis.

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Abstract

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The thesis explores global and national-level issues related to the development of markets for biomass for energy. The thesis consists of five separate papers and provides insights on selected issues.

The aim of Paper I was to identify methodological and statistical challenges in assessing international solid and liquid biofuels trade and provide an overview of the Finnish situation with respect to the status of international solid and liquid biofuels trade. We found that, for the Finnish case, it is possible to qualify direct and indirect trade volumes of biofuels. The study showed that indirect trade of biofuels has a highly significant role in Finland and may be a significant sector also in global biofuels trade.

The purpose of Paper II was to provide a quantified insight into Finnish prospects for meeting the national 2020 renewable energy targets and concurrently becoming a large-scale producer of forest-biomass-based second-generation biofuels for feeding increasing demand in European markets. We found that Finland has good opportunities to realise a scenario to meet 2020 renewable energy targets and for large-scale production of wood-based biofuels. The potential net export of transport biofuels from Finland in 2020 would correspond to 2–3% of European demand.

Paper III summarises the global status of international solid and liquid biofuels trade as illuminated by several separate sources. International trade of biofuels was estimated at nearly 1 EJ for 2006. Indirect trade of biofuels through trading of industrial roundwood and material by-products comprises the largest proportion of the trading, with a share of about two thirds. The purpose of Paper IV was to outline a comprehensive picture of the coverage of various certification schemes and sustainability principles relating to the entire value-added chain of biomass and bioenergy. Regardless of the intensive work that has been done in the field of sustainability schemes and principles concerning use of biomass for energy, weaknesses still exist.

The objective of Paper V was to clarify the alternative scenarios for the international biomass market until 2020 and identify the underlying steps needed toward a well-functioning and sustainable market for biomass for energy purposes. An overall conclusion drawn from this analysis concerns the enormous opportunities related to the utilisation of biomass for energy in the coming decades.

Keywords: biomass trade, international biomass trade, biomass resources, biomass production

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List of papers

This thesis is based on the following appended papers:

I **Methodological aspects on international biofuels trade: international streams and trade of solid and liquid biofuels in Finland**
J. Heinimö
Biomass and Bioenergy, 2008, 32(8): 702–716

II **Renewable energy targets, forest resources, and second-generation biofuels in Finland**
J. Heinimö, H. Malinen, T. Ranta, & A. Faaij
Biofuels, Bioproducts and Biorefining, 2011, 5(3): 238–249

III **Production and trading of biomass for energy – an overview of the global status**
J. Heinimö & M. Junginger
Biomass and Bioenergy, 2009, 33(9): 1310–1320

IV **Evaluation of sustainability schemes for international bioenergy flows**
M. Mikkilä, J. Heinimö, V. Panapanaan, L. Linnanen, & A. Faaij
International Journal of Energy Sector Management, 2009, 3(4): 359–382

V **Views on the international market for energy biomass in 2020: results from a scenario study**
J. Heinimö, V. Ojanen, & T. Kässi
International Journal of Energy Sector Management, 2008, 2(4): 547–569

Co-authorship statement

Jussi Heinimö is the main author of papers I, II, III, and V. Paper IV is co-authored with Mirja Mikkilä, who conducted the testing of the coverage of various certification schemes and sustainability principles. Heinimö contributed the development of the tri-dimensional approach and commented on Paper IV. In Paper III, Martin Junginger provided data and contributed editing of the overviews of wood pellet and ethanol markets. Ville Ojanen contributed the development of an approach based on application of a group support system for Paper V. Professor Tapio Ranta supervised work for papers I, II, and III, and Professor André Faaij supervised work on papers I, II, III, and IV. In addition, Professor Lassi Linnanen supervised work for Paper IV and Professor Tuomo Kässi supervised the work on Paper V. Adjunct Professor Heikki Malinen provided supervision and comments for Paper II.

Related projects

During the work on this thesis, the author was involved in the following projects:

Task 40 – Sustainable International Bioenergy Trade: Securing supply and demand, IEA Bioenergy, 2004–

International bioenergy trade: business opportunities and forecasting the effects for Finland, Finnish Funding Agency for Technology and Innovation (Tekes), 2004–2007

GLOENER – Global Forest Energy Resources, Sustainable Biomass Supply and Markets for Bioenergy Technology, Finnish Funding Agency for Technology and Innovation (Tekes), 2007–2009

Energy Technology Cluster Programme, Ministry of Employment and the Economy, 2007–

Related publications (not included in this thesis)

Heinimö, J. & Alakangas, E. 2006. Solid and liquid biofuels markets in Finland – A study on international biofuels trade. Research report EN A-53. Department of energy and environmental technology. Lappeenranta University of Technology. 92 p.

Heinimö, J., Pakarinen, V., Ojanen, V. & Kässi, T. 2007. International bioenergy trade – Scenario study on international biomass market in 2020. Research report 181. Department of Industrial Engineering and Management, Lappeenranta University of Technology. 42 p.

Peksa-Blanchard, M., Dolzan, P., Grassi, A., Heinimö, J., Junginger, M., Ranta, T. & Walter, A. 2007. Global Wood Pellet Markets and Industry: Policy Drivers, Market Status and Raw Material Potential. IEA Bioenergy Task 40. 120 p.

Heinimö, J. 2008. IEA Bioenergy Task 40, 'Sustainable International Bioenergy Trade: Securing supply and demand', Country report of Finland 2008. Research report EN A-57. Department of Energy and Environmental Technology. Lappeenranta University of Technology. 32 p.

Junginger, M., Bolkesjø, T., Bradley, C., Dolzan, P., Faaij, A., Heinimö, J., Hektor, B., Leistad, Ø., Ling, E., Perry, M., Piacente, E., Rosillo-Calle, F., Ryckmans, Y., Schouwenberg, P.–P., Solberg, B., Trømborg, E., da Silva, W.A. & de Wit, M. 2008. Developments in international bioenergy trade and markets – results from work of IEA Bioenergy Task 40. *Biomass and Bioenergy*, 32(8): 717–729.

Heinimö, J. & Alakangas, E. 2009. Market of biomass fuels in Finland. Research Report 3. Institute of Energy Technology. Lappeenranta University of Technology. 35 p.

Heinimö, J. 2010. Evaluation of the worldwide sawdust potential available for pellet production. In *The Pellet Handbook: The Production and Thermal Utilisation of Biomass Pellets*, ed. Obernberger, I. & Thek, G. Earthscan, pp. 383–391.

Asikainen, A., Anttila, P., Heinimö, J., Smith, T., Stupak, I. & Ferreira Quirino, W. 2010. *Forest and bioenergy production. In Forest and Society – Responding to Global Drivers of Change*, IUFRO World Series Vol. 25, ed. Mery, G., Katila, P., Galloway, G., Alfaro, R., Kanninen, M., Lobovikov, M., & Varjo, J. pp. 183–200.

Heinimö, J., Malinen, H., Ranta, T. & Faaij, A. 2011. Forest biomass resources and technological prospects for the production of second-generation biofuels in Finland by 2020. Research report 11. Institute of Energy Technology. Lappeenranta University of Technology. 23 p.

Panapanaan, V., Hämäläinen, A., Mikkilä, M., Linnanen, L. & Heinimö, J. 2011. Sustainability criteria for biomass – views of Finnish stakeholders. *International Journal of Energy Sector Management, 5(2): 307–326.*

Conference proceedings

Heinimö, J. & Ranta, T. 2005. International Biomass Trade in Finland: review of the status and future prospects. 14th European Biomass Conference and Exhibition, 17–21 October. Paris, France.

Ojanen, V., Heinimö, J., Pakarinen, V., Kässi, T. & Ranta, T. 2006. Assessment of future visions of international biomass markets. International Conference on Management of Innovation and Technology, 21–23 June. Singapore.

Heinimö, J. & Junginger, M. 2007. Production and trading of biomass for energy – An overview of the global status. 15th European Biomass Conference & Exhibition, 7–11 May. Berlin, Germany.

Kässi, T., Heinimö, J. & Ojanen, V. 2007. Observations from scenario studies on biomass market and distributed energy. 15th European Biomass Conference & Exhibition, 7–11 May. Berlin, Germany.

Heinimö, J., Ojanen, V. & Kässi, T. 2007. Challenges and opportunities of international biomass market – Findings from a scenario study. Bioenergy 2007, 3rd International Bioenergy Conference and Exhibition, 3–6 September. Jyväskylä, Finland.

Heinimö, J. & Ranta, T. 2008. International Biofuels Trade in Finland – Trends in 2004–2006 and future views. World Bioenergy 2008 Conference, 27–29 May. Jonköping, Sweden.

Table of contents

Abbreviations and terms

Abbreviations

Symbols and acronyms

BTL	biomass-to-liquid
CN	combined nomenclature
CO_2	carbon dioxide
DME	dimethyl ether
ETBE	ethyl-tertio-butyl-ether
F-T	Fischer-Tropsch
HS	harmonized commodity description and coding system
ITP	integrated thermal processing
RES	renewable energy sources

Units

J	Joule
l	litre
m	metre
m^3	cubic metre (solid cubic metre unless other mentioned)
t	metric ton
yr (yrs)	year (years)
W	Watt
%	Percent

Prefixes with exponent values

c	centi	10^{-2}
M	mega	10^{6}
G	giga	10^{9}
T	tera	10^{12}
P	peta	10^{15}
E	exa	10^{18}

Terms

Bioenergy

Bioenergy refers to energy derived from biofuel.

Biomass

Refers to the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste.

Biofuel (=biomass fuel)

Fuel produced directly or indirectly from biomass. The fuel may have undergone mechanical, chemical or biological processing or conversion or it may have had a previous use. Biofuel refers to solid, gaseous and liquid biomass-derived fuels.

Energy biomass

Refers to biomass that is utilised for energy purposes.

Energy wood

Energy wood consists of stem wood that is not suitable (i.e., has too small diameter or is too low quality) for the forest industry. The term ‘small-diameter energy wood’ is used for wood that does not meet the size requirement for pulpwood and is harvested for energy use.

Forest chips (forest fuels)

Wood fuel in which raw material has not previously had another use. Forest fuel is taken from the forest and processed directly for energy use. Forest fuels can be fuels from logging and thinning, and they can be made from logging residues, as well as stumps and rootstocks.

Logging residues

Woody biomass residues created during the harvesting of merchantable timber. Logging residues include tree tops with branches and can be salvaged fresh or after seasoning.

Log

Log refers to round wood that is used as raw material for sawn timber and plywood.

Pulpwood

Round wood suitable for manufacturing pulp. Not usually good enough for sawmilling. Pulpwood is usually wood that is too small, or of inferior quality to be used for sawmilling. The commonly applied minimum diameter for pulpwood in Finland is 6–9 cm.

Pulp chips

Wood chips that regarding their quality can be used as raw material in pulp manufacturing. Pulp chips are made from bark free raw materials.

Raw wood

Raw wood refers to round wood (domestic and imported) and imported (non-domestic) wood chips used as raw material in the forest industry.

Second-generation biofuel

Refers to liquid biofuels produced from cellulose, hemicellulose, or lignin.

1 Introduction

Global supply of energy faces several increasing challenges. Energy consumption is on a moderate increase, especially in rapidly developing countries. The overall size of the world energy market nearly doubled over the last 40 years (1971–2008), driven by rapid expansion in energy use in the developing world, where populations and energy activity have grown. The International Energy Agency (IEA) has projected an increase in primary energy demand of 1.6% per year until 2030, when the cumulative increase will be equal to half of the current demand. (IEA, 2008, 2010)

Increased international awareness of climate change has led to greater international collaboration on environmental issues. Most industrialised countries have, in ratifying the Kyoto Protocol, committed themselves to a significant decrease in greenhouse gas emissions up to 2012. In light of the latest United Nations Climate Change Conferences and the ambitious targets of the European Union (EU) for renewable energy, work to mitigate climate change will remain a strong trend in the coming decades. One of the most important means of reaching this goal is to increase the share of renewable energy in total energy consumption. In addition, efforts to decrease dependence on fossil fuels and to diversify and ensure the energy supply are important in promoting the use of renewable energy sources.

Biomass, the focus of this thesis, has potential to become a more important source of energy as the century progresses and fossil fuels become scarce and more expensive. A vital, well-functioning, and international biomass market will be one key factor in combining the growing demand and production potential for biomass. This thesis explores a set of global and national issues related to the development of markets for energy biomass[1].

1.1 The role of biomass in energy production – global and national perspectives

Fossil fuels – oil, coal, and natural gas – dominate the world energy economy, accounting for more than 80% of today's total primary energy supply (see Table 1).

[1]Biomass that is utilised for energy purposes.

Renewable energy sources accounted for 13% (67 EJ) of the world's total primary energy demand in 2008 (IEA, 2011). The widespread non-commercial use of biomass in developing countries makes it by far the greatest source of renewable energy (51 EJ), with approximately 60% of energy biomass used for cooking and heating in developing countries (IEA, 2008). The remaining energy use of biomass takes place in industrialised countries, where biomass is utilised both in industrial applications within the heating, power, and road transportation sectors and for heating purposes in the private sector.

Table 1: *Various energy sources in relation to the world's total primary energy supply in 2008 (IEA, 2011)*

Source of energy	Energy (EJ)	Share
Oil	170	33%
Coal and peat	139	27%
Natural gas	108	21%
Combustible renewables and waste	51	10%
Nuclear energy	30	6%
Hydropower	12	2%
Others	4	1%
Total	514	100%

Biomass fuels provide approximately 1% of global electricity production, and it is often used in combined heat and power production. The global biomass power generation capacity is approximately 45 GW. Global consumption of liquid biofuels in transportation came to 1.0 EJ in 2006, of which North America accounted for 46%, Latin America for 27%, and the EU for 23%. The share of biofuels in total global consumption for transport was about 1%. (IEA, 2008)

Generally, biomass has been a marginal source of energy in industrial applications, but in some countries with a large forest-industry sector, such as Sweden, Finland, and Austria, forest biomass is an important source of energy. For example, in Finland, renewable energy sources cover roughly a quarter of total primary energy consumption and approximately 80% of renewable energy is derived from wood (Statistics Finland, 2009).

1.2 The market for energy biomass

Several studies have researched the production potential of biomass for energy at local, regional, and global level; see, for example, (Berndes et al., 2003). The use of biomass for energy production will increase especially strongly in the industrialised nations which are aiming to decrease emissions of greenhouse gases, e.g. in the EU (The European Parliament and the Council, 2009). The market for biofuels is developing rapidly and becoming more international. For example, the areas from which biofuels are procured, especially by large biomass-users, are expanding quickly, and more biomass than before is being sourced from abroad, including from other continents.

It has been observed that some areas have a biomass potential that exceeds their own consumption and that in some other areas the demand for energy biomass surpasses the local production potential (Ranta, 2005; Smeets et al., 2007). Consequently, some areas seem to be becoming net suppliers of energy biomass to areas that have fewer biomass resources. However, a prerequisite for the continuation of this development is that biomass can be produced for energy in these areas at competitive costs also against other energy options.

Although biomass has the potential to become a more important source of energy, a substantial increase in energy use of biomass requires parallel and positive development in several sectors, and there will be plenty of challenges to overcome. Price competitiveness and security of supply are important conditions for the growth of biomass in energy supply. The decisions made by politicians, the strategies of market actors, and the direction of research activities will have a significant influence on the development of the biomass market, and, because of this, several stakeholders and other parties have ambitions to contribute to the development of the market. To support the positive development of the market and for making the most of that development, a more comprehensive understanding of the market is needed.

1.3 Research issues and outline of the thesis

The overall objective of this thesis is to analyse the challenges and opportunities for the development of energy biomass markets at international and national level. The thesis provides insights on selected issues of energy biomass markets: the challenges related to identifying the status of international trade of biomass for energy purposes at the global and national level, implications for the development of the forest industry and the production of second-generation biofuels, the coverage of various certification schemes and principles of sustainability in the value chain of bioenergy, and future views of international energy biomass markets. The major research questions of the thesis are:

Paper I: What are the major methodological and statistical challenges in observing the international solid and liquid biofuels trade, particularly in the Finnish case?

Paper II: Can Finland meet the national 2020 renewable energy targets and concurrently become a large-scale producer of forest-biomass-based second-generation biofuels for feeding increasing demand in European markets?

Paper III: What is the total volume of internationally traded energy biomass?

Paper IV: What is the coverage of various sustainability schemes and initiatives of the entire value chain of bioenergy, from production to end use?

Paper V: What are the scenarios for the global biomass market until 2020, and the underlying steps needed toward a vital, well-functioning, and sustainable market for biomass to be utilised for energy purposes?

The work done for the thesis was closely linked with a collaboration project entitled Task 40, ‘Sustainable International Bioenergy Trade: securing supply and demand’, carried out within the framework of the IEA Bioenergy agreement. Task 40 has the vision that the global bioenergy market will develop, over time, into a true ‘commodity market’ that will ensure supply in a sustainable way. A vital and well-functioning international biomass market will be one of the key elements combining the production potential and growing demand for biomass. Increased knowledge of energy biomass markets and application of new tools will contribute to the development of the markets.

Assessing internationally traded energy biomass volumes is difficult for several reasons. For example, many biomass streams are traded for raw-material purposes but ultimately end up in energy production. Paper I identifies methodological and statistical challenges in observation of international solid and liquid biofuels trade. The paper includes a comprehensive analysis of indirect import (and export) of biofuels that takes place in the forest industry with its procurement of raw wood[2]. The paper sets out to determine the status of international biofuels trade in Finland more accurately than have earlier works and is an attempt to exemplify an approach that can be applied in similar studies. From the experience gained from the review of the Finnish situation, the paper gives recommendations for development of the statistics concerning biofuels trade.

In Paper II, the focus is on the local, country-level, context and implications of a developing biomass market. The commercialisation of second-generation biofuels has been recognised as a prerequisite for meeting the EU's 2020 renewable energy targets and allowing more ambitious targets anticipating 2030. The forest industry cluster has several interesting opportunities for the production of second-generation biofuels. Recent studies have indicated that second-generation biofuels made from forest biomass may become economically attractive by 2020 when compared to conventional biofuels (Lensink and Londo, 2010; Londo et al., 2008; McKeough and Kurkela, 2007, 2008). Paper II 1) includes a comprehensive state-of-the-art analysis of expected bioenergy demand and supply for Finland by 2020, taking dynamics in the forest and forest-industry sectors into account and 2) highlights the possibilities for large-scale production of second-generation biofuels in Finland, interlinked with description of the most recent (industrial) developments in that area.

Paper III expands the overview of international energy biomass trade provided in papers I and II to the global context. Paper III summarises the status of international biofuels

[2] Raw wood refers to round wood (domestic and imported) and imported (non-domestic) wood chips used as raw material in the forest industry.

trade as illuminated by several separate sources and provides insight into the most important energy biomass trade streams (industrial raw wood, wood pellets, and bio-ethanol).

During recent years' rapid expansion of international energy biomass trade, sustainable production and utilisation of biomass for energy has become a crucial issue. A great deal of effort has been undertaken to develop tools and systems for promoting sustainable biomass production and utilisation. Currently, dozens of certification schemes and sustainability principles for biomass can be found, see e.g., (van Dam et al., 2008; Zarrilli, 2006). However, the majority of these biomass and bioenergy principles are not widely used and have not yet received status of certification scheme. The existence of various principles and criteria sets does not guarantee sustainable biomass production and utilisation for energy if they do not cover the entire value-added chain. The purpose of Paper IV is to outline a comprehensive picture of the coverage of various certification schemes and sustainability principles related to the entire value-added chain of biomass and bioenergy and to compare them accordingly.

The development of the international biomass market is a very broad issue whose general characteristics are 1) complexity, 2) uncertainty, and 3) interdependence. Scenario planning is one of the methods applied most frequently for evaluation of future development routes. The purpose of Paper V is to clarify the alternative scenarios for the international biomass market until 2020 and identify underlying steps needed toward a vitally functioning and sustainable market for biomass for energy purposes.

2 Methodological approach

The work in this thesis makes use of several methodological approaches. The methodology in the various papers has been selected for its appropriateness for the research issue at hand. Most of the research questions were motivated by the aim to increase understanding of the development of energy biomass markets and to contribute to their development. It is hoped that the findings described in the thesis will be useful for various stakeholders of biomass markets.

2.1 The approach in the studies

In Paper I, a procedure to identify the most relevant energy biomass streams is developed and tested. The method utilises information from statistics to determine the status of international energy biomass trade at national level, with Finland as a case study.

In Paper II, the dynamics of supply and demand of forest biomass are examined on the basis of the reviews of three projections of the production and wood sourcing for the forest industry. The components included in the review are 1) forest industry wood streams, 2) forest growth and forest industry harvesting potential, and 3) forest biomass harvested for energy. In the review, streams of stem wood and crown biomass and root wood are distinguished. Technological prospects and outlook for second-generation biofuel production in the Finnish forest industry are reviewed based on the literature and recently published information.

Paper III presents an estimation of the scale of global international trade in biomass for energy in 2004–2006. The estimation includes indirect trade of energy biomass within the forest industry’s raw wood (the challenge of assessing indirect trade of energy biomass is presented in detail in Paper I). The analysis is based on synthesis of statistical information, supplemented with the literature. In addition, the paper includes reviews of the most important global trade streams of energy biomass. The information utilised in the review is collected mainly from the literature and the Internet.

In Paper IV, a tri-dimensional approach (considering sustainability issues, technical biomass conversion routes, and physical trade flows) is developed for testing the coverage of various dimensions of sustainability in different phases of the value-added chain with the chosen certification schemes and sustainability principles. In total, nine sustainability principles and schemes for biomass are selected for review.

In Paper V, scenario processes supplemented by a group support system (GSS) are applied for investigating the future development of the biomass market up to 2020. Two scenario processes were conducted for the study. A heuristic, semi-structured approach, including the use of preliminary questionnaires as well as manual and computerised GSS, was applied in the scenario processes.

The methodological approach of the papers is described in more detail where each paper is presented individually. However, the main methodology, initial data, and calculation steps used in Paper II are described in the following section, as this work has not previously been published in a peer-reviewed publication.

2.2 Main methodology, initial data, and calculation steps for Paper II

2.2.1 Projections for wood use and sourcing for the forest industry

In Paper II, the dynamics of future forest biomass supply and demand are examined on the basis of reviews of projections of the production and wood sourcing for the Finnish forest industry. The projections cover wood streams from annual increment of forests into forest products and energy. In total, three projections were established. The first is the basic projection entitled '2020 METLA', which utilises the results from an extensive study carried out at Finnish forest research institute (METLA) by Hetemäki and Hänninen (2009). The estimations made in the study are based on statistical trends and qualitative analysis of the operating environment and of competitiveness. That study painted a gloomier outlook for forest-industry production in Finland than the other predictions did. According to METLA's forecast, annual production of paper and paperboard will decline by nearly four million tons from 2008 levels by 2020, ending up at almost the same level as in the early 1990s. Production of sawn timber has been forecast to be about 10 million cubic metres in 2020, roughly equalling the figure from 2008. METLA's paper also includes estimated round wood and pulp chip import volumes. The basic projection is supplemented by the projections '2020 b' and '2020 c', which are more optimistic with regard to forest-industry production, assuming the wood use and production of the forest industry to be at the same level in 2020 as in 2007. The idea of the two projections is to illustrate boundary conditions and supply–demand dynamics related to forest biomass. In the projection 2020 b, raw wood import was set at the 2007 level. In the projection 2020 c, imported round wood is substituted for domestic round wood (no import of round wood) but import of pulp chips remains at the 2007 level.[3] Actual forest-industry production in 1990–2008, estimates of forest-industry production until 2020, and the projections are presented in Figure 1.

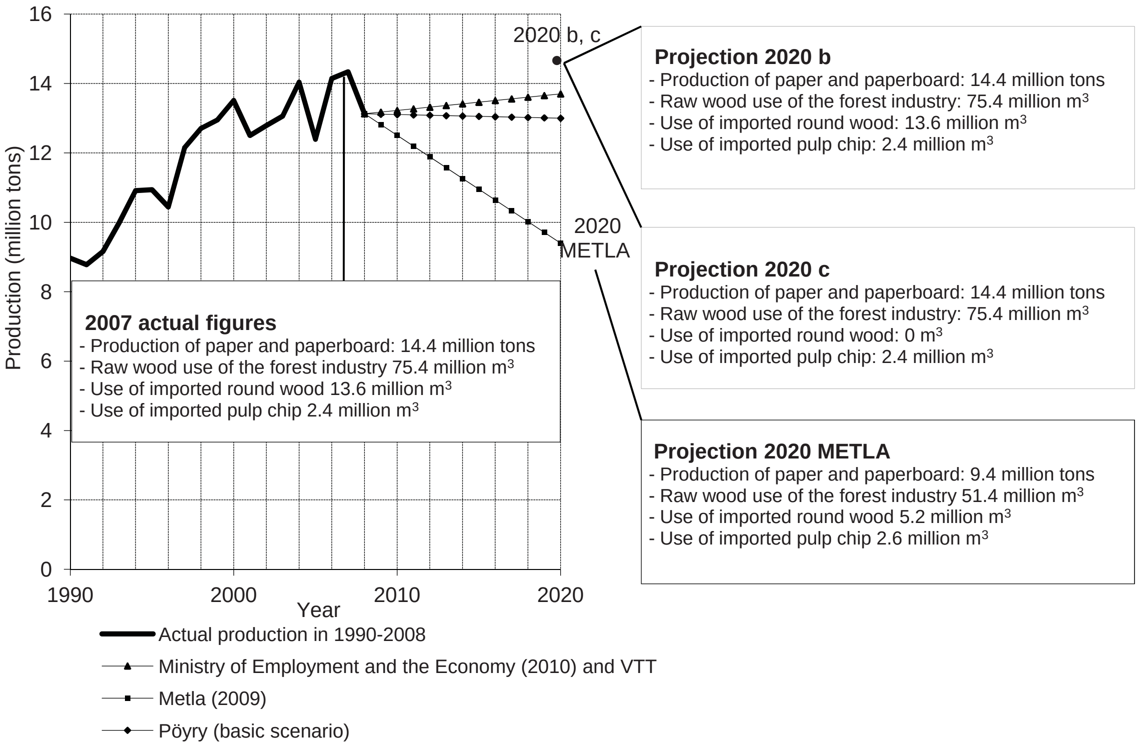


Figure 1. *Production of paper and paperboard in Finland in 1990–2008, forecast to 2020, and the projections reviewed (Hetemäki and Hänninen, 2009; Ministry of Employment and the Economy, 2008; Pekkarinen, 2010).*

[3] The estimate is based on the fact that the Russian export duty for processed wood such as pulp chip is lower than that for unprocessed raw wood.

2.2.2 The components of wood stream review, calculation steps, and initial data used

The components included in the wood stream review are 1) forest-industry wood streams, 2) forest growth and forest biomass harvesting potential, and 3) forest biomass harvested for energy. In the review, streams of stem wood and crown biomass and root wood are distinguished. In addition, raw wood import (and export) is included (in Figure 2). The import of wood for energy in Finland has been negligible – e.g., approximately 0.2 million cubic metres in 2007 (Heinimö and Alakangas, 2009) – in comparison to total wood use; therefore, the import of wood for energy is not considered. In the following sections, the components of the review, calculation steps, and initial data used are described in detail.

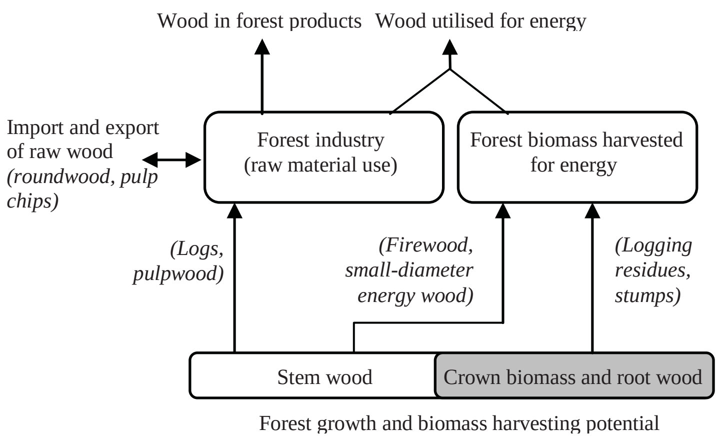


Figure 2. *The components of the wood stream review. The timber assortments included in the review are presented in brackets.*

Component 1: Wood streams in the forest industry

The forest industry procures wood primarily for use as raw material. In the manufacturing of primary products, a significant amount of the wood ends up in energy production or is converted into by-products that are utilised in energy production. An investigation of wood streams in the forest industry is needed for determining how much domestic and imported wood ends up in forest products and energy use. Investigation of the wood streams of the forest industry is done by means of a forest-industry wood stream model that was developed in an earlier study and is described in detail in Paper I. The model takes into account the differences between the various branches of the forest industry in the efficiency of wood's conversion into products. Branch-specific consumption volumes for round wood, imported pulp chips, and indigenous woody by-products in the forest industry and production volumes for sawn timber and plywood are needed as the initial data for the model. Wood use in 2007 in different branches of the Finnish forest industry and assumptions concerning wood use in 2020 in different projections are presented in Table 2.

Table 2: *The use and sourcing of wood for the forest industry in Finland in 2007 and projected to 2020 (figures include bark)*

Year/projection	2007 actual[a] (in Mm^3)	2020 METLA[b] (in Mm^3)	2020 b (in Mm^3)	2020 c (in Mm^3)
Total raw wood use	75.4	51.4	75.4	75.4
Use of indigenous round wood	59.4	43.6	59.4	73.0
Use of imported round wood	13.6	5.2	13.6	0
Use of imported pulp chip	2.4	2.6	2.4	2.4
Wood use in different branches of the forest industry:				
Sawmills				
▪ Domestic round wood (logs)	26.5	20.7	26.5	28.0
▪ Domestic pulp chip	0	0	0	0
▪ Imported round wood (logs)	1.5	1.3	1.5	0
▪ Imported pulp chip	0	0	0	0
Plywood mills				
▪ Domestic round wood (logs)	3.2	3.7	3.2	4.0
▪ Domestic pulp chip	0	0	0	0
▪ Imported round wood (logs)	0.7	0.7	0.7	0
▪ Imported pulp chip	0	0	0	0
Fibre and particle board mills				
▪ Domestic round wood (pulpwood)	0	0	0	0
▪ Domestic pulp chip	0.8	0.8	0.8	0.8
▪ Imported round wood (pulpwood)	0	0	0	0
▪ Imported pulp chip	0.1	0.1	0.1	0.1
Other mechanical wood processing				
▪ Domestic round wood (logs)	0.4	0	0.4	0.4
▪ Domestic pulp chip	0	0	0	0
▪ Imported round wood (logs)	0	0	0	0
▪ Imported pulp chip	0	0	0	0
Chemical pulp mills				
▪ Domestic round wood (pulpwood)	20.2	14.4	20.2	30.0
▪ Domestic pulp chip	7.5	4.0	7.5	7.5
▪ Imported round wood (pulpwood)	9.8	2.4	9.8	0
▪ Imported pulp chip	1.9	1.9	1.9	1.9
Mechanical and semi-mechanical pulp mills				
▪ Domestic round wood (pulpwood)	9.1	4.8	9.1	10.6
▪ Domestic pulp chip	3.1	1.3	3.2	3.2
▪ Imported round wood (pulpwood)	1.5	0.8	1.5	0
▪ Imported pulp chip	0.4	0.6	0.4	0.4

[a] Source (Peltola, 2008).
[b] Source (Hetemäki and Hänninen, 2009), excepting: 1) figures for other mechanical wood processing that are assumed to be zero for simplification of the calculations and 2) figures for chip use by fibre and particle board mills that are assumed.

Component 2: Forest growth and forest biomass harvesting potential

Despite the expansion of the forest industry and increased consumption of round wood over the past five decades, the total volume of growing stock of Finnish forests is on the rise. The annual growth of Finnish forests has been increasing since the 1950s, because of improvements in forest management, and total growth has exceeded total removal since the 1970s. Draining of low-production forest areas on moist peatlands has been an important measure to boost the growth of Finland’s forests. On the basis of extensive national forest inventories, METLA has estimated the annual sustainable removal of logs[4] and pulpwood[5] from Finnish forests in 2007–2016 at 70 million cubic metres. Exceeding the sustainable level means a decrease in future harvesting possibilities. METLA estimated that the sustainable harvesting potential of logs and pulpwood will increase, to about 80 million cubic metres, from 2017 to 2026 (Finnish Forest Research Institute (METLA), 2009).

Timber assortments that are harvested for energy use include energy wood, logging residues[6], and stumps. The energy wood has consisted of stem wood that is not suitable (i.e., has too small a diameter) for the forest industry and is mainly available from first and second thinning. The term ‘small-diameter energy wood’ is used for wood that does not meet the size requirement for pulpwood (normally, the minimum top diameter for pulpwood is 6–9 cm) and is harvested for energy use (often as whole trees). Logging residues and stumps are produced from crown biomass[7] and root wood. In Finland, the majority of firewood (approximately 80%) comes from stem wood: from small-diameter energy wood and wood that fulfils the requirements of pulpwood and logs. The remainder of the firewood is composed of logging residues and residues from sawmilling for household use (Torvelainen, 2009). In this paper, the assumption is that firewood is made solely from stem wood, to simplify the analysis.

[4] Logs are used as raw material for sawn timber and plywood, and they are most valuable forest biomass.
[5] Pulpwood is smaller-diameter logs and is used as raw material for wood pulp.
[6] Woody biomass residues created during the harvesting of merchantable timber. Logging residues include tree tops with branches and can be salvaged fresh or after seasoning.
[7] More precisely, logging residues include over 10% stem wood (tops); however, this fact is not relevant for the results of this study.

Harvesting potential of stem wood

Some forest area is protected, or other environmental restrictions limit the harvesting potential. The biomass growth in these forests comprises non-exploitable forest biomass potential. A small amount of growing stock is lost through mortality. Also, some stem wood that is harvested for logs and pulpwood does not meet the quality and diameter requirements of the forest industry and is left in the forest. The primary source of stem wood loss is the undersized tops, especially in the first thinning (Hakkila, 2004). The increment of stem wood that may be harvested without environmental restrictions but is not harvested comprises untapped stem wood potential. In this paper, sustainable stem wood harvesting potential furthermore includes small-diameter wood that does not meet the diameter requirement for pulpwood. The sustainable potential of small-diameter stem wood corresponds to the technical small-diameter stem wood potential, defined by Hakkila (2004) as five million cubic metres per year. Untapped stem wood potential is calculated by subtracting harvesting volumes of logs and pulpwood and small-diameter energy wood from the sustainable stem wood harvesting potential.

Harvesting potential of crown biomass and root wood

Similarly to stem wood, environmental restrictions and mortality reduce the available volume of crown biomass and root wood. For example, Finnish forest management practices restrict the harvesting of stumps and logging residues from mineral soils (Äijälä et al., 2010). The above-mentioned limitations to harvesting compose the non-exploitable potential. The actual harvesting potential for logging residues and stumps is dependent on the volume of final felling (harvesting volume of logs), whereas the production potential of small-diameter energy wood does not depend on markets for industrial round wood. The initial data and assumptions for review of forest growth and biomass harvesting potential are presented in Table 3.

Table 3: *Initial data and assumptions for increment and harvesting potential of forest biomass divided into stem wood and crown biomass + root wood (figures include bark)*

Parameter / year and projection	2007 actual (in Mm^3)	2020 METLA (in Mm^3)	2020 b (in Mm^3)	2020 c (in Mm^3)
Stem wood:				
Stem wood growth	99	114[a]	114[a]	114[a]
Sustainable harvesting potential	75	85	85	85
▪ *Logs*[b]	*32*	*33*	*33*	*33*
▪ *Pulpwood*[b]	*38*	*47*	*47*	*47*
▪ *Small-diameter stem wood*[c]	*5*	*5*	*5*	*5*
Harvesting of stem wood for raw material (logs and pulpwood)	57.7	43.6	59.4	73.0
▪ *Logs*	*28.0*	*24.4*	*30.1*	*32.4*
▪ *Pulpwood*	*29.7*	*19.2*	*29.3*	*40.6*
Forest-industry use of domestic round wood (logs and pulpwood)	59.4	43.6	59.4	73.0
Crown biomass and root wood:				
Crown and root wood growth[d]	75	86	86	86
Technical harvesting potential for crown biomass and root wood (logging residues and stumps)	10[e]	14[f]	14[f]	14[f]

[a] *The figure is an estimate. Between 1975 and 2007, annual stem wood growth increased from 58 to 99 Mm^3, and on the basis of this trend line, annual stem wood growth in 2020 was forecast to come to 114 Mm^3. The figure is in line with the estimated increase in the sustainable harvesting potential of stem wood (Finnish Forest Research Institute, 2009; Peltola, 2009).*

[b] *Source (Finnish Forest Research Institute, 2009).*

[c] *The figure corresponds to technical harvesting potential for stem wood that does not meet the size requirements for pulpwood – see source (Hakkila, 2004).*

[d] *Assumed to be 75% of stem wood growth, from data available from source (Finnish Forest Research Institute, 2009). The figure corresponds to the ratio of the total mass of dry biomass in stem wood (955 Mt) to the mass of other biomass in living trees (714 Mt).*

[e] *Source (Hakkila, 2004). According to the study, the theoretical harvesting potential for crown biomass and root wood is 36 Mm^3/yr and the technical harvesting potential is 10 Mm^3/yr, of which eight million cubic metres per year is logging residues (including foliage) and two million is from stumps (figures are in solid cubic metres). The theoretical harvesting potential includes all stem wood, crown biomass, and root wood left in the forest in conjunction with timber harvesting. Technical harvesting potential is defined according to the theoretical maximum potential by accounting for technological and environmental limitations, such as that not all crown biomass and root wood can be recovered and forest management guidance does not allow removal of stumps and logging residues on mineral soils.*

[f] *The latest studies (e.g., that of Kärhä et al. (2009)) have indicated greater (14 Mm^3/yr) technical harvesting potential for logging residues and stumps in 2020, on the basis of the looser restrictions for forest chip production that were included in previous forest management practices; e.g., harvesting of stumps is currently allowed also from pine- and birch-dominant forests. Earlier, logging residues were collected only from spruce-dominant final felling. The harvesting potentials of logging residues and stumps in the 2020 projections are assumed to be equivalent to that stated in source (Kärhä et al., 2009). Determining projection-specific technical harvesting potential for logging residues and stumps for 2020 was not considered relevant in this case, because, among other considerations, the harvesting volumes of logs are roughly at the same level in all 2020 projections (±15%) when compared to actual 2007 figures.*

Component 3: Forest biomass harvested for energy

In this paper, forest biomass harvested for energy includes firewood, energy wood, stumps, and logging residues. The calculations concerning wood streams are based on the assumption that the first two of the above-mentioned timber assortments are made from stem wood whereas the latter two are made from crown biomass and root wood. A summary of the volumes of forest biomass harvested for energy is presented in Table 4.

Table 4: *Parameters used for the calculations of forest biomass harvested for energy*

Parameter / year and projection	2007[a] (in Mm^3)	2020[b] (2020 METLA, 2020 b, and 2020 c) (in Mm^3)
Stem wood:		
▪ Firewood	6	5
▪ Energy wood	1	5
Crown biomass and root wood:		
▪ Logging residues and stumps	2	9
Total	9	19

[a] The actual figures for forest biomass harvested for energy were available in forestry statistics (Finnish Forest Research Institute, 2009; Peltola, 2009). In 2007, the use of forest chips came to 2.7 million solid cubic metres, of which approximately two thirds came from logging residues and stumps (Ylitalo, 2008). Energy wood consisted almost solely of small-diameter trees that did not fulfil the size requirement for pulpwood. In the same year, firewood consumption was approximately six million cubic metres. The volume of firewood is defined with a calorific value of firewood assumed to be 8.1 GJ/m^3 (Torvelainen, 2009).

[b] The use of forest chips and firewood in 2020 is set according to the government's targets, at 13.5 million solid cubic metres for forest chips and five million for firewood (Pekkarinen, 2010). The assumption is that the shares of energy wood, logging residues, and stumps in forest fuel consumption will be one third each in 2020 (Kärhä et al., 2009).

3 Challenges in determining the status of trade in biomass for energy

The markets for biomass used industrially for energy purposes are developing toward international commodity markets – wood pellets and fuel ethanol being two examples – and this development can be expected to (see e.g. Junginger et al., 2006; Obernberger and Thek, 2010; Rosillo-Calle and Walter, 2006). Fulfilling the increasing demand, biomass has to be transported longer distances and even imported from other continents. Already, in some EU member states, bioenergy use is largely based on imported biomass, and some countries have significant plans for a major increase in biomass import and processing for energy purposes.

Comprehensive information on international trade of energy biomass is important for market actors, policymakers, and other stakeholders aiming to contribute to the development of biofuels markets for increasing the energy use of biomass. An explicit need has been recognised for identifying the status of biofuels trade, resulting from the following facts, among others: biofuels markets are developing rapidly, statistics offer weak information on international trade of biomass intended for energy purposes, and no international organisations regularly compile comprehensive statistics on the subject.[8]

The volumes of international solid and liquid biofuels trade were investigated at the European level in 1999 within the AFB-net project (Vesterinen and Alakangas, 2001). Since then, several country-specific studies on biofuels trade have been carried out – e.g., that of Ericsson and Nilsson (2004) – and since 2006 within IEA Bioenergy Task 40. Comparison of the earlier studies' results is not straightforward, particularly because of the different procedures addressing the products that are traded in forms other than fuels but are finally used in energy production. For example, the Finnish forest industry imports wood as raw material; however, only some of this wood can be refined into forest products – the rest is utilised for energy. Some studies included only the products that were traded for energy purposes and solely used as a fuel (Vesterinen and Alakangas, 2001). Some studies have expanded the concept, taking some biomass

[8] For example, Hillring and Trossero (2006) have considered the available statistics on wood fuels trade in their study .

streams that were not traded for energy, but ended up in energy production into account (Ericsson and Nillsson, 2004; Junginger and Faaij, 2005). In such cases, the study easily becomes complex.

A significant number of cross-border streams that include biomass in diverse forms can be found. These streams of biomass – raw, processed, or within products – together with their various end-use purposes constitute a complex field. Imported biomass or a product that includes biomass can be processed in the import country into more refined final products, which are then consumed within the country or exported forward. Foreign biomass that has entered the country can be used as fuel (e.g., wood pellets). Nevertheless, some products, such as ethanol or some forest industry by-products, can be used for both energy and raw material purposes, which makes it necessary to know where the products are consumed. Biomass is also traded for biofuel production, as in the case of palm oil for biodiesel, and in the future this may be a more common trend when large biorefineries produce liquid biofuels for transport sector. Eventually, most of the products that include biomass end up in recycling and energy production.

When the definition of (solid, liquid or gaseous) biofuel is considered, biomass becomes biofuel when it is purchased for energy use or, in some cases, when it is consumed in energy production[9]. The simplest procedure to determine the status of import and export of biofuel is to consider only the products that are traded directly for energy purposes. Nevertheless, the actual trade and streams of biomass that are closely related to the energy use of biomass are larger and should be considered. Otherwise, the overall view of international biofuels trade will remain too narrow. On the other hand, the examination will become complex if it includes all biomass streams, such as forest products, agricultural products, and biodegradable wastes, until the carbon they contain is oxidised into CO_2. With the above-mentioned factors taken into account, the detailed investigation of all exported and imported biomass streams may not be relevant.

[9] Black liquor is a good example. It is a by-product of the process of making wood pulp and contains non-fibrous wood matter and ‘cooking’ chemicals. The energy production from black liquor is a solid part of the pulp-making process, but the main reason for burning black liquor is to recover and recycle the cooking chemicals from the pulp-making process.

3.1 Paper I: Methodological aspects on international biofuels trade: international streams and trade of solid and liquid biofuels in Finland

3.1.1 Scope and method

The purpose of Paper I was to provide an overview of the Finnish situation with respect to the status of import and export of (solid and liquid) biofuels. Parallel to this, the study aimed to identify methodological and statistical challenges in observing international biofuels trade. In Paper I, Finland was selected as the country under review. Finland is a large importer of raw wood. Foreign wood represents over one fifth of the forest industry's wood use, and, consequently, a significant percentage of biofuels produced and consumed in the forest industry physically originates from abroad (in 2004).

Currently, ethanol, vegetable oils, fuel wood, charcoal, and wood pellets are the most important products that are traded internationally for energy purposes. Nevertheless, the international trade of these products is much smaller than the international trade of biomass for other purposes. Table 5 compares the scales of international trade of agricultural products, wood-based biomass connected to the forest industry, and biomass traded for fuel purposes.

Table 5: *An overview of the international trade of selected agricultural products, wood based biomass, and biomass fuels in 2006*

Type of Biomass	Annual volume of international trade
Agricultural products:[a]	
▪ Grains (wheat, barley, oats, rye)	154 Mt
▪ Maize	95 Mt
▪ Vegetable oils (palm, soy, rape, sunflower)	51 Mt
Biomass related to forest industry:[a]	
▪ Industrial round wood	129 Mm^3 (~100 Mt)
▪ Sawn timber	133 Mm^3 (~60 Mt)
▪ Paper and paperboard	114 Mt
Biofuels:	
▪ Wood pellets[b]	4 Mt
▪ Fuel wood[a]	4 Mm^3 (~3 Mt)
▪ Charcoal[a]	1 Mt
▪ Ethanol[c]	4 Mm^3 (~3 Mt)

[a] *Source: (FAOSTAT data, 2011)*
[b] *Source:(Heinimö and Junginger, 2009)*
[c] *Source: (Beghin et al., 2007; Renewable Fuels Association, 2009)*

In view of the complexity of mapping all potential biomass streams until the carbon they contain is oxidised into CO_2 and keeping the target of finding an approach that can in the future be applied with a reasonable contribution to determining the status of international biofuel trade forest products, food and fSHodder and municipal waste were excluded from the review. The study covers all remaining biomass streams: 1) biofuels (products that are traded for energy production, such as fuel ethanol, wood pellets, and firewood), 2) raw materials that are traded for manufacturing of biofuels (e.g., sawdust and pulpwood that is used in pellet production or pre-processed biomass used in the production of liquid biofuels), and 3) raw wood (wood matter that is used in the manufacture of forest products).

The forest industry imports wood primarily to be used as raw material. Nevertheless, during the manufacturing of the primary products, a considerable amount of the raw wood ends up in energy production or is converted into by-products that are utilised in energy production. Biofuel purchase and use of this kind is referred to in this study as indirect import of biofuels[10], and corresponding export is called indirect export of biofuels. The wood streams described above jointly constitute indirect trade of biofuels.

Determining the status of international biofuels trade involves first reviewing various statistics (foreign trade, energy, forestry, and waste statistics) that may include relevant data. After that, cross-border biomass streams were considered by means of statistics for foreign trade. Since indirect trade is taken into account, the extent to which the products under review end up in energy production must be evaluated, for which purpose the wood streams in the Finnish forest industry are investigated in more detail. To this end, an Excel-based spreadsheet model was composed. By means of the model, wood streams that end up in energy production, raw material use, and final products were calculated for the various branches of the forest industry. The model takes into account the differences between these branches in the efficiency of their conversion of wood into products. After that, the mass and energy balances of international biofuels trade are determined via the information from foreign trade statistics and the wood streams

[10] The indirect import of biofuels has previously been considered by Ericsson and Nillson (2004).

determined for the forest industry. The paper includes comprehensive discussion of the methods applied and the accuracy of the results.

3.1.2 Main findings

Determining internationally traded biofuel volumes is difficult for several reasons. First of all, many biomass streams are traded as raw materials but finally end up in energy production. In the Finnish case, raw wood import constitutes the most important stream of indirectly imported biofuels. Given the above observation, indirect trade may be a significant sector of global biofuels trade. Secondly, data on the direct and indirect trade of biofuels are disparate and often must be derived indirectly from several statistics. The information obtained from Foreign Trade Statistics data did not give, in this case, clear figures for the import and export of biofuels; therefore, more detailed investigation was necessary, despite the large number of Combined Nomenclature (CN) codes – e.g., wood pellets are recorded under the same CN code as wood waste. Energy and horticultural peat are under the same code, as well. Also several products of the chemical industry, including ETBE[11], have the same CN code. Third, biomass streams can have several end uses – for example, ethanol as a raw material of the chemical industry or as a transportation fuel. The main weaknesses in the Foreign Trade Statistics data are that they do not differentiate the end-use purposes of the materials between energy and raw material use, and various products can be included under a single CN code.

In Finland, the total direct import and export of solid and liquid biofuels, being mainly composed of wood pellets and tall oil, is tiny in comparison with the total consumption of biofuels. By contrast, indirect trade, especially indirect import of wood fuels, is of considerable importance in the Finnish energy system. The study showed the largest biofuels stream to be composed of raw wood, which is used as raw material in the forest industry, and that as much as 45% of the raw wood imported to Finland in 2004 ended up in energy production. The total international trade of solid and liquid biofuels was evaluated at 72 PJ, of which the majority, 59 PJ, was traded with raw wood. About 22% (66 PJ) of wood-based energy in Finland originated from imported wood. Tall oil and wood pellets constituted the largest export streams of biomass fuels.

[11] ethyl-tertio-butyl-ether. ETBE is an additive that enhances the octane rating of petrol.

3.1.3 Conclusions and discussion

The study showed that for the Finnish case, it is possible to quantify direct and indirect trade volumes for biofuels. However, this requires a number of restrictions and qualifications.

Forest products, food and fodder, and municipal waste were excluded from the scope of the study. Certainly the largest influence on the balance of biofuels trade would have been the consideration of forest products in the calculations. If forest products had been included in the consideration of the balance of biofuels trade, the outcome might have been different, because of the high total export of forest products from Finland. On the other hand, as a result of raw wood import, about a fifth of the biomass within exported forest products originates abroad. However, evaluation of the extent to which exported forest products eventually end up in energy production and in which countries was excluded from the scope of the study. Recovered fuels and biogas include fractions that originate abroad and were once imported to the country as food, fodder, or refined forest products.

The procedure applied in this study – first reviewing the structure of biomass use and the main biomass streams and then focusing a more detailed investigation on the most relevant biomass streams – can be regarded as an appropriate approach for determining the status of international biofuels trade.

International and Finnish statistics should be further developed, to take into better consideration international biofuels trade. If the biofuels that are covered by CN codes that can include several products had their own codes in the system, the Foreign Trade Statistics data would be more useful. However, it may not be realistic to expect that the CN system could categorise a product under different codes according to its end uses. The Finnish energy statistics already separate out international biofuels trade. These statistics include, *inter alia*, data on the export of energy peat and wood pellets. In addition, since the statistics for 2004, an estimation of the indirect import of wood fuels has been included, calculated by means of the methodology developed in this study. In addition, a separate CN code for wood pellets was introduced in 2009.

Internationally, biofuels markets are developing rapidly, with the EU being one of the forerunners. Export and import of biomass for energy purposes will grow with the use of bioenergy. One of the emerging sectors for liquid biofuels is road transportation. The increasing production of transport fuels from biomass, such as biodiesel and ETBE, will increase the import and export of biomass for energy use and thus change the balance of international biofuels trade in several countries. In addition, the increasing use of biofuels in the road transport sector will make the monitoring of international biofuels trade more challenging and problematic, because some liquid biofuels will be traded as blends with fossil motor fuels.

Finally, it should be kept in mind that export and import volumes of biomass are only one element in the larger markets for biomass. For one to learn more about the markets and be able to foresee their alternative development routes, further studies need to be conducted on the biofuels streams and driving factors behind them, covering the chain of bioenergy from biomass resources to energy products. Pressure for a certification system for biomass used for energy purposes is increasing. The certification of biomass ensures that biomass is produced in a sustainable way and includes a chain of custody tracking, which will provide data that are needed for observation of the state of the international biofuels trade.

4 Local context and implications of energy biomass trade

In Finland, the energy use of biomass has steadily increased since the 1970s. The successful utilisation of biomass has largely been based on the forest industry, in which raw wood's consumption and production have been on the increase in recent decades. Finnish forest resources have been growing ever since the 1950s, and since the 1970s the total removal of forests has remained below the limit of sustainable harvesting potential (Peltola, 2008). Nevertheless, the Finnish forest industry's use of wood exceeds the harvesting potential, and the past few years have seen almost a quarter of the raw wood consumed by the Finnish forest industry (Finnish Forest Research Institute, 2009) being imported. On account of raw wood import, a significant proportion of Finnish bioenergy is based on imported biomass.

Over the past few years, the European pulp and paper industry has suffered from excess capacity in production, stemming from the weakened global economy, success of electronic communication, and stagnating European paper markets (Confederation of European Paper Industries (CEPI), 2010; Sipilä et al., 2009b). In Finland too, the forest industry was harmed by the weak global economy. The Finnish forest industry is now undergoing major structural change, and the volume of the industry's production is forecast to drop dramatically as 2020 nears, especially in comparison to 2007's all-time peak figures (Hetemäki and Hänninen, 2009; Reini et al., 2010). The industry faces a situation where new business opportunities are seen as a solution for improving the sector's long-term competitiveness (Sipilä et al., 2009a; Sipilä et al., 2009b).

The forest-industry cluster has several interesting opportunities for the production of second-generation biofuels, such as options for process integration and utilisation of existing raw material sourcing organisations and facilities (Joelsson et al., 2009; Mäkinen et al., 2006; Sipilä et al., 2009a). Synthetic diesel production with gasification and Fischer-Tropsch (F-T) synthesis, dimethyl ether (DME) production at pulp mills, and bio-oil production with integrated fast pyrolysis (ITP) are regarded as most promising technologies for producing liquid fuels from woody biomass within the forest industry (Joelsson et al., 2009; Sipilä et al., 2009a). The price developments for energy and forest products have increased the forest industry's interest in the production of biofuels. The price of energy is increasing while prices of paper and paperboard have been declining (Sipilä et al., 2009b). For example, in Finland in 2000–2007, the price index for energy increased by 53% (Hetemäki, 2009). In the same time, the unit price of exported paper products fell by 20% (Hetemäki, 2009).

4.1 Paper II: Renewable energy targets, forest resources, and second-generation biofuels in Finland

Recent studies have indicated that second-generation biofuels made from forest biomass may become economically attractive by 2020 when compared to conventional biofuels (Lensink and Londo, 2010; Londo et al., 2008; McKeough and Kurkela, 2007, 2008). As an EU member state, Finland has committed itself to the 10% biofuel target for the transport sector. However, its cold climate has given Finland unfavourable conditions for cultivation of the oil and sugar crops used for production of conventional liquid biofuels. Production of second-generation biofuels from forest biomass by 2020 is defined as one target in the Finnish Climate and Energy Strategy (Ministry of Employment and the Economy, 2008).

4.1.1 Scope and method

The purpose of Paper II was to provide quantified insight into Finnish prospects for meeting the national 2020 renewable energy targets and concurrently becoming a large-scale producer of forest-biomass-based second-generation biofuels for response to increasing demand in European markets. The focus of the paper is on assessing the potential for utilising forest biomass for liquid biofuels up to 2020. In addition, technological issues related to the production of second-generation biofuels within the forest industry are reviewed. The paper establishes its scope initially via a review of Finnish renewable energy targets and the outlook for the forest industry. The dynamics of future forest biomass supply and demand are examined on the basis of reviews of projected production and wood sourcing for the Finnish forest industry. Next, a comprehensive picture of wood streams, covering the chain from forest increment to end use of wood as raw material and energy, and raw wood import, is composed. Then, the technological prospects and plans for second-generation biofuels in the Finnish forest industry are reviewed. The results are presented and evaluated, and, finally, conclusions and recommendations based on the presented findings are given.

4.1.2 Main findings

In 2006–2010, the forest industry permanently closed down a capacity corresponding to nearly three million tons of pulp, paper, and paperboard in Finland. According to the forecast by METLA that was utilised in the basic projection applied in this paper, production of paper and paperboard in Finland will decline by 2020 to almost the level it saw in the early 1990s. In parallel with this, volumes of forest-industry by-products and the energy derived from those by-products will fall. As part of the work toward the renewable energy targets set for 2020, the government is striving to increase the annual use of forest fuels by approximately 10 million solid cubic metres from the level that prevailed in 2007.

As a result of improvements in forest management, the growth of forest biomass is increasing in Finland and the annual sustainable harvesting potential of stem wood will increase by 10 million cubic metres in 2007–2020. Despite the increasing use of forest fuels, the declining wood use of the forest industry and increasing harvesting potential of stem wood will lead to a situation in which considerable oversupply of stem wood (especially for pulpwood) exists in Finland in 2020. With the rate of utilisation of pulpwood, logging residues, and stumps set at 80%, an additional 15 million cubic metres of wood (13 million m^3 of pulpwood and two million solid cubic metres of logging residues and stumps) could be allocated for energy purposes. Then, in total, 15 million cubic metres of wood would be used for biofuel production, enabling approximately 80 PJ/yr (1.8 Mt/yr) of synthetic biofuel production.

However, the opportunities to utilise forest biomass for second-generation biofuel production are ambiguous. Decreasing forest-industry production reduces the volumes of the forest industry’s energy by-products (black liquor, bark, and sawdust), and much less energy will be derived from by-products in 2020 than was estimated in the government’s strategy. Compensation for the latter gap, if implemented solely via increased use of forest biomass energy, requires that about half (7 Mm^3/yr) of the under-utilised wood potential be allocated for heat and power production in 2020. Then approximately seven million cubic metres of wood would remain available for biofuels, enabling 40 PJ/yr (0.9 Mt) in synthetic biofuels’ production. Taking the existing biofuel production capacity (20 PJ/yr) and national biofuel consumption target (25 PJ) into account, one finds that the potential net export of second-generation biofuels from Finland in 2020 would be 35 PJ (0.8 million tons), corresponding to approximately 2–3% of European demand for biofuels in transport.

Production of liquid biofuel from forest biomass offers opportunities to develop new bioenergy business within the forest industry. Finland's major forest industry companies have invested in commercialising second-generation biofuel production technologies that use forest biomass as raw material. From the standpoint of commercialisation of biomass-to-liquid (BTL) technologies, the opportunities for efficient process integration that enables high, over 70%, total conversion efficiency are a key advantage over separate BTL plants for the forest industry. Decisions on construction of the first industrial-scale BTL plants within the forest industry will be made after the processes are proved on the current pilot scale. Nevertheless, economic factors will have the pivotal role in the decisions. Biofuel production has to be profitable business for the companies, and the risk associated with this costly investment should be at an acceptable level.

4.1.3 Conclusions and discussion

As a whole, Finnish forest biomass resources, their utilisation (for raw material and energy), and the technological issues related to second-generation biofuel production within the forest industry involve a great deal of complexity, uncertainty, and interdependence. The essential factors for realising the scenario of large-scale second-generation biofuel production and meeting the renewable energy targets in Finland are

- commercialisation of second-generation biofuel production technologies,
- a high utilisation rate for the sustainable harvesting potential for forest biomass, and
- use of some pulpwood harvesting potential for energy purposes.

The factors that would support the above scenario are

- mobilising the resources of other renewable energy sources, such as wind energy and agro-biomass, and
- importing biomass for energy purposes.

Given the options for utilising forest biomass for large-scale production of second-generation biofuels, the following elements affect the results (wood streams).

First, the paying capacity in various pulpwood end-use sectors (the forest industry, biofuel production, heating and power plants, and pellet mills) in 2020 will determine the actual consumption volumes for pulpwood in these sectors. Furthermore, production subsidies for small-diameter energy wood, for example, and other energy policy measures – such as emission trading, energy taxes, and investment grants – will affect wood markets.

Second, approximately half (7 Mm^3) of the volume of pulpwood, logging residues, and stumps that will, in theory, become available by 2020 as a result of the decrease in the wood use of the forest industry and the increased growth of forests is needed to compensate for the decline in energy production from forest-industry by-products (black liquor and solid processing residues). Otherwise, the government's target for total wood energy cannot be met. On the other hand, the use of other renewable energy sources, such as agro-biomass or wind energy, could be increased from the current target levels. However, the development of the use of various renewable energy sources is highly dependent on energy policy measures.

5 The global context of energy biomass trade

Despite the current minor contribution (approximately 10%) of bioenergy to the global energy mix, biomass has potential to contribute much more significantly to the global energy supply in the long run. Dozens of studies have been carried out to estimate the potential for harvesting energy from biomass. A review of the 17 studies carried out by Berndes et al. (2003) revealed greatly differing estimates of the contribution of biomass to the global energy supply, from below 100 EJ/yr to above 400 EJ/yr in 2050. Later, several new studies tackled the issue (see e.g. Hoogwijk, 2004; Hoogwijk et al., 2005; Smeets et al., 2004). In the most optimistic scenarios, biomass meets more than the current global energy demand, without competing with food production, forest production, and biodiversity. In total, the expected contribution to the world's primary energy supply could be in the range of 250–500 EJ/yr (Junginger et al., 2006). A recent literature review by Dornburg et al. (2008) investigated how factors such as food supplies, water use, biodiversity, energy demands, and agro-economics affect these potentials. Their main conclusion was that, even with strict criteria and excluding areas with water stress or high biodiversity value, a minimum of 250 EJ/yr is likely available. The largest biomass production potential will lie in large-scale energy plantations in areas with a favourable climate for maximising the production of biomass. Latin America, Sub-Saharan Africa, and Eastern Europe, along with Oceania and East and North-East Asia, have the most promise to become important producers of biomass in the long term.

In the ideal case, figures on international trade of solid and liquid biofuels are available directly from international statistics, but in practice this is often not the case, despite a multitude of international authorities, agencies, institutions, and enterprises compiling and publishing biomass and biomass product statistics. As Paper I was revealed at the country level, determining international trade volumes for solid and liquid biofuels is difficult for several reasons. First, many biomass streams are traded for use as materials but ultimately end up in energy production. Second, biomass streams can have several final applications; examples are palm oil (feedstock for biodiesel or for food applications) and ethanol (transportation fuel or feedstock for the chemical industry). Third, some biomass fuels, such as wood pellets and bio-ETBE, have been recorded in aggregate form by foreign trade statistics. For example, wood pellets were recorded under the same code as wood waste in the EU's trade statistics, making it difficult to assess the exact volume. Paper III makes an attempt to clarify the present status of the global energy biomass trade.

In parallel with the growing energy biomass market, many scholars and policymakers have recognised both positive and negative consequences of biomass and biofuels trade, see e.g., (Buchholz et al., 2007; Elghali et al., 2007; Krotscheck et al., 2000; Lewandowski and Faaij, 2006; Stupak et al., 2007; van Dam et al., 2008; Zarrilli, 2008). On one hand, increasing biomass production can lead to positive socio-economic effects; for example, it would bring new income to poor areas that have favourable conditions for large-scale biomass plantations, as in South-East Asia and Latin America. On the other hand, the increased production of biomass and biofuels can stimulate, whether directly or indirectly, the deforestation of indigenous rainforests and carbon emission from those areas. Similarly, labour conditions in some regions, such as Asia, are often questionable and may be unacceptable on large-scale biomass plantations. These undesirable effects in some production areas have sparked debate among importing countries, particularly in Europe, on the sustainability of biomass production for energy uses. In recent years, dozens of sustainability principles and certification schemes have been introduced for biomass that are aimed at ensuring that production and utilisation of biomass take place in a sustainable manner and mitigate the above-mentioned negative effects, see e.g., (van Dam et al., 2008). However, the existence of various sustainability principles may not necessarily guarantee sustainable production and utilisation of biomass; e.g., they may not cover the entire value-added chain from primary production to end-use. Paper IV focuses on these issues from a global perspective.

5.1 Paper III: Production and trading of biomass for energy – an overview of the global status

5.1.1 Scope and method

The work in Paper III was motivated by the lack of good statistics on global trade in (solid and liquid) biofuels. While for some markets (e.g., those for wood fuels, ethanol, and vegetable oils) separate overviews exist, e.g., (Alakangas et al., 2007; Carriquiry et al., 2008; Ericsson and Nillsson, 2004; Hillring, 2006; Kaltschmitt and Weber, 2006;

Walter et al., 2008), no comprehensive overview is available for global biomass trade. The aim of Paper III was to summarise trade volumes for various biomass types used for energy as illuminated by several separate sources. Paper I considered indirect trade of biofuels (within raw wood) and, judging from the Finnish case review, revealed that indirect trade may be a significant sector in global biofuels trade. In Paper III, indirect trade of biofuels was further discussed and the scope expanded to global context.

The examination of international biofuels trade becomes complicated if all biomass streams, including forest products, agricultural products, and biodegradable wastes, are counted. It is fairly easy to determine the calorific values of the above-mentioned products in the state in which they cross a national border. However, determining to what extent a country's bioenergy production is based on imported forest products, food, fodder, and municipal waste is problematic. Paper I analysed indirect trade of biofuels within the forest industry. Globally, a remarkably large volume of raw wood that the forest industry consumes is imported from abroad. On average, 40–60% of round wood can be converted into forest products in the forest industry. The rest remains as by-products such as black liquor, bark, sawdust, and chips, that have no feasible raw material use within the forest industry. The biomass categories included in the overview of Paper III are equivalent to those in the country-specific review in Paper I:

- Biofuels (products traded for energy production, such as fuel ethanol, wood pellets, and firewood)
- Raw materials that are traded for manufacturing of biofuels (e.g., sawdust and pulpwood that is used in pellet production or pre-processed biomass that is used in the production of liquid biofuels)
- Raw wood (wood matter that is used in the manufacturing of forest products)

Furthermore, Paper III reviews the status of international trade of agricultural, forestry, and bioenergy commodities and compares the current volume of international solid and liquid biofuels trade to its long-term potential. A crucial factor for the prospective growth of international trade of biomass for energy is the regional imbalance between supply and demand. In many areas, regionally and nationally, the biomass production potential cannot meet the demand. Typical examples are industrialised countries such as EU members, the USA, and Japan. On the other hand, there are areas where biomass production potential exceeds local demand, such as many parts of Sub-Saharan Africa and Latin America. Taking the local production and usage potential into account, Hansson et al. (2006) have estimated the global potential for solid and liquid biofuels trade flow between different regions of the world in 2050 to be 80–150 EJ in favourable conditions, which can be viewed as a theoretical upper limit for international biofuels trade.

5.1.2 Main findings

Ethanol, vegetable oils, fuel wood, charcoal, and wood pellets are the most important products that currently are internationally traded for energy purposes. Nevertheless, the international trade of these products is much less than international trade of biomass for other purposes (forestry and agricultural commodities). Most of the biomass products reviewed are mainly consumed locally in the countries of production, but in the case of products such as sawn timber, paper and paperboard, palm oil, and wood pellets, a considerable proportion of the total production is exported.

International trade of solid and liquid biofuels was estimated to be about 0.9 EJ for 2006. Indirect trade of biofuels through trading of industrial roundwood and material by-products constitutes the largest proportion of trading, having a share of about 0.6 EJ. The remaining amount consisted of products that are traded directly for energy purposes, with ethanol, wood pellets, and palm oil being the most important commodities. The trading of energy biomass represents approximately 5% of the total use of biofuels in industrialised countries (see Table 6). In 2004–2006, the volume of indirect trade of biofuels did not change remarkably. In contrast, direct trade of solid and liquid biofuels is growing rapidly (by more than 50% over a three-year period). In view of the estimated total volume of internationally traded biofuels, biomass trade is still a long way from its estimated long-term maximum of 80–150 EJ/yr.

Table 6: *The estimated scope of international trade of biofuels in 2004–2006 (PJ), excluding tall oil, ETBE, and waste*

Year / product	2004	2005	2006
Indirect trade:	580	640	630
▪ Industrial roundwood[a]	450	490	480
▪ Wood chips and particles[b]	130	150	150
Direct trade:	190	230	300
▪ Ethanol[c]	70	80	120
▪ Biodiesel[d]	2	7	15
▪ Fuel wood[e]	40	40	40
▪ Charcoal[f]	20	20	20
▪ Wood pellets[g]	30	40	60
▪ Palm oil[h]	30	40	40
Total	770	870	930

[a] *Round wood in FAO statistics (FAOSTAT data, 2009) is without bark, so 10% bark was added. Other assumptions: average density of 0.8 t/m^3, 45% average conversion into biofuels, and calorific value of 9.4 GJ/t.*

[b] *Assumptions: average density of 0.8 t/m^3, 45% average conversion into biofuels, and 9.4 GJ/t calorific value.*

[c] *Assumed calorific value: 27 GJ/m^3.*

[d] *Authors' estimate based on sources (Carriquiry et al., 2008; Port of Rotterdam, 2008). Assumed calorific value: 37 GJ/t.*

[e] *Assumed density and calorific value of 0.7 t/m^3 and 13 GJ/t.*

[f] *Assumed calorific value: 22 GJ/t.*

[g] *Assumed calorific value: 17.5 GJ/t.*

[h] *According to source (Indexmundi, 2007), the EU-25 and China have by far the greatest industrial consumption of palm oil among the countries that have no palm oil production of their own. The assumptions made for the estimation were that in 2004–2006 the EU was the only significant user of palm oil for energy among the countries with no palm oil production of their own and that in the EU the oleo chemical industry's use of palm oil has been 0.3 Mt/yr, with the rest used for energy purposes. These assumptions and data from source (United States Department of Agriculture, 2009) give 0.7 Mt for the trade volume of palm oil for energy in 2004, 1.0 Mt in 2005, and 1.1 Mt in 2006. The calorific value of palm oil was assumed to be 37 GJ/t.*

Forest biomass is the main raw material of the forest industry and has an important role as a source of bioenergy. Industrial round wood is a rather local product. More than 90% of the industrial round wood produced is consumed locally in the countries in which it is produced. However, industrial round wood is one of the most important biomass products in world trade and unprocessed wood is being shipped increasingly to markets further from where it is harvested. In 2009, the total trade volume of industrial round wood was 129 million cubic metres. The major wood importing regions are East-Asia (mainly China and Japan) and the Nordic countries. Russia, Eastern Europe, Oceania, and North America are the main exporters.

The production and international flow of wood pellets may involve one of the most successfully traded biomass commodities. We estimate that in 2006 more than eight million tons of wood pellets were produced, globally; 6.4 Mt of wood pellets may have been produced in Europe, compared to about 1.2 Mt in Canada and 0.8 Mt in the USA. In 2006, the majority of global wood pellet production (and consumption) took place in Europe. The volume of international trade of wood pellets was estimated at 3.6 Mt in 2006. North America (especially Canada), the Baltic countries, and Finland have been the most important exporters of wood pellets, while Sweden has been their most important country of import. However, the pellet market is developing quickly and rapidly growing pellet markets (and import) can be found, e.g., in several EU countries.

Bio-ethanol is a commodity that has been produced and traded globally in large volumes for decades. The ethanol market is well developed, as is the logistics infrastructure in many countries. For decades, Brazil was the world's largest producer and consumer of ethanol, but it was surpassed by the USA in 2005. These two countries dominate the ethanol market, producing 70% of the world's ethanol. In 2006, global bio-ethanol production totalled 51 giga litres. In ethanol trading, Brazil is the largest exporter, with the USA and the EU being, correspondingly, the largest importers. In 2006, the total trade of ethanol was estimated to be 4.3 giga litres, with Brazil (3.5 Gl) as the main exporter, while the USA, Japan, and the EU were the main importers.

5.1.3 Conclusions and discussion

The analysis showed that the amount of directly traded solid and liquid biofuels is increasing greatly, in some cases even showing exponential growth in recent years. This holds especially for liquid biofuels (ethanol and biodiesel), for which demand is growing tremendously in the EU and the USA, and which has triggered the export of ethanol (mainly from Brazil), vegetable oil (e.g., palm and soybean oil), and biodiesel from South-East Asia and Latin America. Also, pellet exports from Canada to the EU (next to large-scale intra-European trade) show strong growth rates. Given current policy developments involving attempts to stimulate the use of biofuels in, for example, the EU and US and in view of increasing fossil oil prices, the increase in trade can be expected to continue far into the future. It is expected that direct trade volumes will overtake indirect trade. Policy will affect international biomass trade in other ways also;

examples include development of sustainability criteria for biofuels (as recently introduced in the RES Directive (The European Parliament and the Council, 2009)) and the changing trade tariffs for commodities such as ethanol.

In the course of the work on Paper III, it became clear that high-quality statistics on global solid and liquid biofuels trade are often unavailable, and figures had to be indirectly estimated or based on expert opinions. The findings of this paper, supplemented by the outcome of the IEA Bioenergy Task 40 workshop (Sikkema et al., 2008), point to the main reasons for this as being

- the indirect trade flows, which cannot be assessed (directly) via trade statistics and whose examination requires details on biomass flows and conversion patterns;
- the fact that in many cases (e.g., for ethanol and vegetable oil), the final end use (energy, feedstock for the chemical industry, or food) is not known when the commodity is traded; and
- the lack of proper CN/HS codes to distinguish dedicated biofuels – for wood pellets and biodiesel, this has been addressed recently, but for advanced refined biofuels (e.g., torrefied pellets, pyrolysis oil, and second-generation Fischer-Tropsch diesel), it may be relevant in the future.

5.2 Paper IV: Evaluation of sustainability schemes for international bioenergy flows

5.2.1 Scope and method

The aim of various certification schemes and sustainability principles for biomass (production and utilisation) is to promote sustainable utilisation of biomass and mitigate related negative effects. Earlier studies to investigate merits of the certification schemes and sustainability principles were mainly focused on either 1) outlining issues of sustainability of biomass production and of that sustainability's assessment, see, e.g., (Buchholz et al., 2007; Elghali et al., 2007; Krotscheck et al., 2000) or 2) analysing or reviewing recommendations, guidelines, certification systems, sets of sustainability criteria, and other synthesis publications on the sustainable use and management of biomass and bioenergy production and trade; see, e.g., (Lewandowski and Faaij, 2006;

Stupak et al., 2007; van Dam et al., 2008; Zarrilli, 2008). The existence of various sustainability principles and sets of criteria may not guarantee sustainable biomass production and utilisation of energy if they do not cover the entire value-added chain; primary production of biomass, the processing of biomass, the production of bioenergy, and that energy’s final use. The previous studies have not attempted to analyse the applicability of various schemes from the angle of actual biomass and bioenergy flows. Proceeding from the above premise, one can see that existing initiatives and schemes may not cover the whole value-added chain and grey areas may exist between the various systems, allowing uncontrolled use of, and trade in, biomass and bioenergy. With these questions at the fore, the work for Paper IV was conducted in order to obtain a comparative evaluation of the different schemes and to determine how each of these schemes fulfils its sustainability attributes.

First, a simplified model describing the import and domestic production, processing, and consumption, as well as the export, of biomass and bioenergy was drawn. In the model, biomass and bioenergy flows are classified according to their origin. ‘Foreign’ and ‘imported’ biomass refer to biomass that has grown abroad, outside the borders of the country of reference.

Second, the various certification schemes and sustainability principles that promote the sustainable production of biomass and bioenergy were preliminarily examined, with some selected for more detailed review. In all, eight certification schemes and sustainability principles, plus the draft version of the EU’s RES Directive, were selected for qualitative review. The selected sets are

- two sustainability principles for the production of agricultural biomass: 1) the Roundtable on Sustainable Palm Oil (RSPO) and 2) the Roundtable on Responsible Soy (RTRS);
- two certification schemes for the production of forest biomass: the Forest Stewardship Council (FSC) (set 3) and a national application, the Finnish Forest Certification System (FFCS) (set 4);

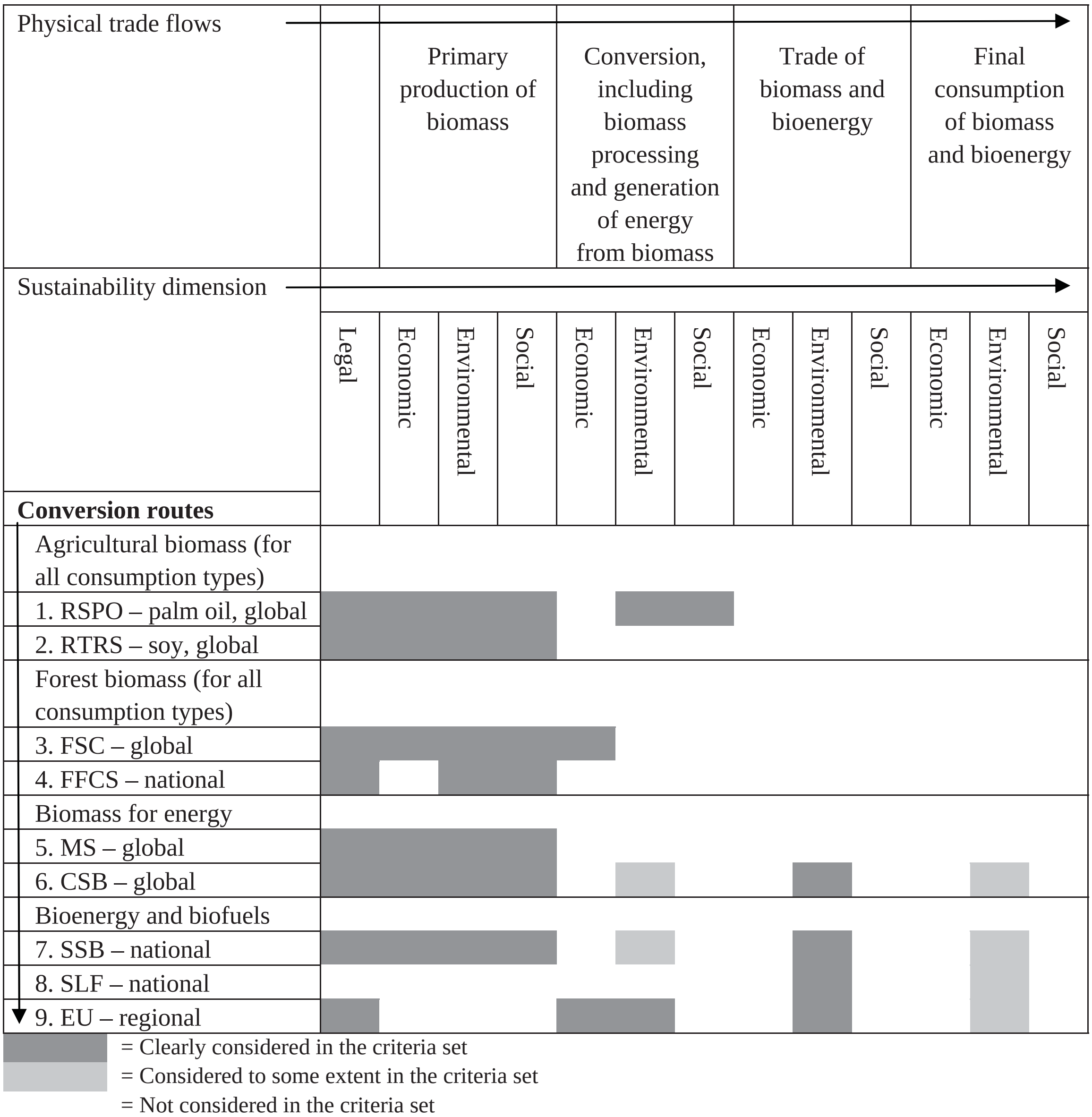
- two initiatives for schemes for certification of biomass as energy raw material: the Harmonised Sustainable Biomass Certification Scheme, called the Meta Standard (MS), driven by the World Wide Fund for Nature (WWF) (set 5), and the Dutch Criteria for Sustainable Biomass (CSB), as set 6; and
- two sustainability principles and one draft directive for bioenergy and biofuels: 7) the German Sustainability Standards for Bioenergy (SSB), 8) the proposed requirements for the Finnish Swan Labelling of Fuel (SWL), and 9) the draft directive of the European Union on promotion of the use of energy from renewable sources.

Third, a tri-dimensional model for qualitative comparison of the chosen sets was drafted. The model of biomass and bioenergy flows provides two dimensions: 1) conversion routes (biomass, biofuel, and bioenergy) and 2) physical trade flows (production, trade, and consumption). These dimensions were complemented with 3) the common sustainability issues (economic, environmental, and social criteria) and their legal framework. The coverage of various sustainability dimensions in different phases of the value added chain with the selected certification schemes and sustainability principles is assessed by means of the approach described above.

5.2.2 Main findings

Comparison of the certification schemes and sets of criteria selected demonstrated that they have some weaknesses and do not cover the entire value-added chain (see Table 7).

Table 7: *A summary of the coverage of the certification schemes and sustainability principles studied*



The application of the schemes and criteria seems to place great emphasis on the primary production of biomass. The majority of the systems focus on resources because that was their original objective. For example, soy, sugar, and palm oil are commodities used for many applications. This does not reduce their relevance for bioenergy trade chains, but additional measures are needed for covering the full chain of custody.

The trade issues seem generally to be assessed from the perspective of greenhouse gas (GHG) balance, which is, obviously, one of the major consequences of increasing trade in commodities. However, trade in biomass, bioenergy, or any other commodity also has diverse economic and social effects. So far, these issues have seldom been recognised within the schemes studied. The parts of the value-added chain related to biofuels and bioenergy processing and trade were emphasised less. Regardless of the focus on primary production, most of the schemes examined did recognise the relevance of taking the whole bioenergy chain into account, but this has remained at the level of rhetoric so far.

The schemes sometimes seem to ignore that utilisation of renewable energy does not on its own guarantee positive or neutral climate impact and may not be economically sustainable; bioenergy is often more expensive than energy generated from fossil energy sources. Likewise, the majority of these schemes have been designed to assess a certain part of the production, trade, and consumption chain. The economic criteria of the sets studied were focused mainly on the micro level consequences of the production and processing of biomass, emphasising a fair reimbursement level for the producers and employees. However, when considering the macro level impact, they very much ignore economic sustainability. Biomass production and processing for energy can be supported and subsidised via various governmental instruments and incentives, such as direct subsidies and tax benefits.

5.2.3 Conclusions and discussion

The main conclusion is that, regardless of the intensive work that has been done in the field of sustainability schemes and principles of biomass for energy, weaknesses still exist. The tri-dimensional model presented in this study is a framework that could be applicable for facilitating, for example, policymakers' formulation of policies that cover all dimensions of sustainability related to biomass and bioenergy throughout the value-added chain. A critical approach is required when one considers the consumption and trade dimensions of the model. Consumption is an activity based on the consumers' own free will. Some of them may favour certified products, but one can ask whether an influence should be brought to bear on consumption in general or it should instead be allowed to respond to market forces. Additionally, considering economic and social sustainability issues in the context of the trade dimension of the model is justified, but the verification of these elements would be clearly challenging.

It was observed that most of the sets of criteria studied were at the policy level and that the implementation of sustainability criteria in practice was highlighted to a lesser degree. Comprehensive sustainability schemes do not promote sustainability without an efficient implementation scheme.

In some cases, the utilisation of biomass for energy can be very expensive in comparisons to fossil fuels. In these cases, subsidised bioenergy production is not economically justified, and its economic sustainability can be questioned.

This paper focused on free trade in biomass and bioenergy, and on the use of various criteria sets or schemes as means to promote sustainable production and utilisation in the global market. However, most biomass and biofuel is used domestically. When applied within a market based system, the efficiency of certification criteria and sustainability principles depends on domestic consumers' interest in certified products. For example, Finnish consumers rely heavily on the sustainable management of their country's natural resources but there has been little demand for certified domestic forest products from the Finnish consumers. In such cases, domestic markets can and should be governed by legal and policy instruments, such as legislation, subsidies, taxes, and training.

6 Prospects for the international energy biomass market

The use of biomass for energy purposes can be increased remarkably during the 21st century. This increase requires parallel and positive development in several areas, and there will be plenty of challenges to overcome. A vital and well-functioning global biomass market will be an essential element combining the production potential and growing demand for biomass.

Several stakeholders and other parties have ambitions to contribute to the development of the biomass market. For example, IEA Bioenergy Task 40 has a vision of the global bioenergy market developing over time into a real ‘commodity’ market. The work on the task has involved, among other elements, discussion of driving forces and prime causes behind the current development of the biomass market and identified potential barriers to market development, see, e.g., (Faaij and Domac, 2006; Faaij et al., 2005).

A comprehensive understanding of the market dynamics is needed for the market players and interest groups to support the development of the international biomass market and make the most of the development. For example, there should be an increase in awareness of factors affecting future development and in the level of knowledge of interactions between the markets for energy biomass and bio-products.

Paper V approaches the issue of future development of the biomass market by means of the scenario planning process. Scenario planning is one of the most frequently applied methods of evaluating future development routes. Several earlier scenario-based studies have investigated the future development of energy and environmental issues on a global scale. For instance, the Intergovernmental Panel on Climate Change (IPCC) has created scenarios focusing on the future development of greenhouse gas emissions (2000). In addition, Brown et al. (2001) have studied scenarios emphasising a clean energy future. Their study concentrated on how the clean energy technologies are able to address the challenges of the energy and environment sector. Also Shell has utilised scenarios to identify opportunities and challenges in the global business environment (Shell, 2005).

6.1 Paper V: Views on the international market for energy biomass in 2020: results from a scenario study

6.1.1 Scope and method

The main objective with Paper V was to clarify the alternative future scenarios for the global biomass market until 2020 and, on the basis of the scenario process, identify underlying steps needed toward a vital, functional, and sustainable market for energy biomass. The sub-objectives that are addressed in the research are to determine and analyse the main factors influencing the development of the biomass market.

Scenario planning is a structured strategic planning method that is used to make flexible long-term plans. It is applied in policy planning; in organisational development; and, more generally, when strategies must be tested against uncertain future developments. Scenario planning is a method for learning about the future by understanding the nature and impact of the most uncertain and important driving forces affecting the future. Scenario processes can be implemented flexibly in many ways and by using different manual and computerised group work methods or decision support systems in processes. Usually, scenario planning yields 3–5 diverging scenarios descriptive of a future situation.

Two equivalent scenario processes were employed for this study. The first was carried out with a group of Finnish experts, and the second involved an international group. A heuristic, semi-structured approach, including the use of preliminary questionnaires as well as manual and computerised group support systems, was applied in the scenario processes. Figure 3 depicts the process that was followed in two separate and partly parallel processes.

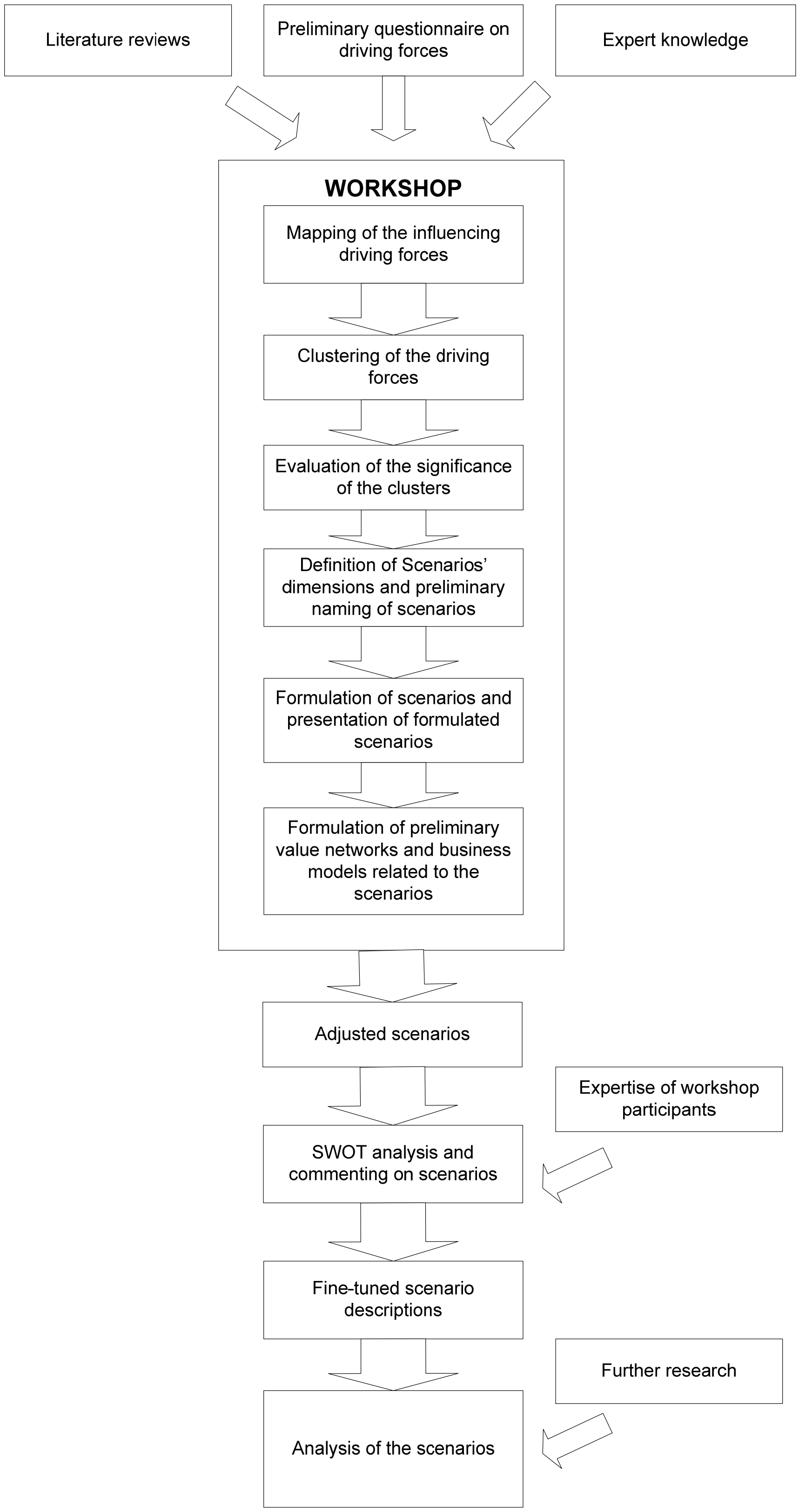


Figure 3. *Phases of scenario processes applied in the study.*

A significant portion of the work was completed in two equivalent intensive one-day workshops that included the phases from ‘Mapping of the driving forces’ to ‘Formulation of preliminary value networks and business models’. The participants represented various interest groups for the bioenergy market, including companies, authorities, research and development organisations, and academia. The scenario process can be seen as a heuristic process (Schoemaker, 1991) including intuitive and systematic elements, and it can also been seen as a ‘participative’ scenario process (Rotmans et al., 2000), where business decision-makers and policy-makers also play a significant role and thus, does not involve a small group of technical experts only, who would be responsible for design and development of scenarios. In the international scenario workshop, four scenarios were drafted. The Finnish workshop for one crafted three preliminary scenario descriptions. After the workshops, the scenarios were complemented and analysed. The process as a whole takes several months to go through.

6.1.2 Main findings

Reviewing the scenarios and the intermediate results of the processes, including the preliminary questionnaire, driving forces, and clusters, enables identification of the scenarios that will lead to the most desired outcome. Correspondingly, the worst scenarios can be identified. The international biomass market is a broad issue, and, depending on the position and viewpoint of the stakeholder, analysis will yield various outcomes as the most desired scenario.

One strong similarity can be found between the scenarios created by the international and the Finnish experts: all scenarios foresee increased utilisation of biomass as an energy source. In addition, all scenarios include a few other common features that can be regarded as critical factors determining the future development of the biomass market:

- Price competitiveness of bioenergy
- Energy policy (taxation, subsidies, and R&D)
- Imbalance between biomass supply and demand (resources)
- International agreements

- Sustainability issues related to the utilisation of biomass
- Strong development of liquid biofuels in the coming years

At the global level, the fundamental requirement for a well-functioning international biomass market is the removal of trade barriers. A strong policy is needed to guide actions toward global and sustainable development of the biomass market. At a regional level, such as in the EU, national subsidy schemes for bioenergy often distort the market for biomass and result in several separate market areas for biomass. The global biomass market has to be seen as an opportunity, and countries should recognise the importance of worldwide co-operation to ensure the positive development of the global biomass market. A well-functioning certification system ensuring that biomass is produced in a sustainable way is seen as a needful tool to promote the market. Dissemination of information to consumers is important because positive public opinion has a strong influence on politicians. It is impossible to develop the biomass market if, at the customer level, biomass is regarded as an unsustainable energy source. The attention must be paid to research and development activities, which should concentrate on the development of production technologies and make use of the potential of new raw-material resources (e.g., crops) as well as on business opportunities. In the EU, the emphasis should be shifted from national energy policy measures toward harmonised subsidy systems for bioenergy. Furthermore, the import of biomass to the union should not be limited by political measures but be seen as a cost-effective and sustainable measure for reaching the challenging climate targets. Also strong coupling of environmental elements and biomass market development is necessary.

The scenarios estimated that the biomass market will develop and grow rapidly as well as diversify in the future. The scenario analysis shows the key issues in the field: global economic growth that includes increasing need for energy, environmental forces in the global evolution, the potential of technological development in solving global problems, capabilities of the international community to find solutions for the global issues, and the complex interdependencies of all these driving forces.

6.1.3 Conclusions and discussion

An overall conclusion drawn from this scenario analysis is that of the enormous opportunities related to the utilisation of biomass as a resource for global energy use in the coming decades. The current use of bioenergy is about 50 EJ/yr, and the potential of biomass as an energy source in 2050 ranges from the current level of use to 400 EJ/yr. This range is so wide that serious questions arise in relation to conclusions based on these analyses.

In general, scenarios differ from forecasts and they should be considered more as tools for strategic planning. Scenarios are possible routes to the future. They do not represent any kind of probabilities related to future development. The scenarios created give only one overview of how the use of bioenergy and biomass markets may look in 2020. Despite this, these scenarios offer a good overall view of the alternative future states of the international biomass market and therefore suggest that, rather than there being just one possible path to take, there are several, alternative ways. The creation of the scenarios does not mean that one and only one scenario will be the reality in 2020; in fact, scenarios may be realised in parallel. This may help to identify possible future events and development in the coming decades.

The scenarios composed exclude prediction of the magnitude of the future volume of international energy biomass trade. However, at its best, the scenario process can aid in facilitating and structuring the interaction between an organisation and its environment, sharing and disseminating individuals' personal knowledge, illuminating future possibilities and threats, and building a holistic understanding of the alternative views of the future.

The scenarios created in the study reinforce the picture of the future of the international biomass market as a complex, multi-layered subject. Many credible alternative future states show that the biomass market will develop and grow rapidly as well as diversify. The results of the scenario process also open new discussion and provide new information and collective views of experts for the purposes of policymaking. For firms, the scenarios provide knowledge that can be utilised in strategic decision-making and, e.g., in technology roadmapping of alternative future development routes. The tentative scenarios at firm level need to be focused on more precise action scenarios and on ways to develop new business models and innovative product and service concepts for dealing with the challenges of the future in the international biomass market.

7 Further research and concluding remarks

This thesis has analysed the development of the energy biomass market internationally and at the national level. The analyses provided tools for contributing to the development of the energy biomass market and improved understanding of how the energy biomass market will develop over the course of this century.

International and Finnish statistics could be further developed to take international biofuels trade into fuller consideration. The increasing use of biofuels in the road transport sector will make the monitoring of international biofuels trade more challenging and problematic, because some liquid biofuels will be traded in blended form, in combination with fossil motor fuels. It is recommended that studies similar to those described in Paper I be carried out for other countries for determining the shortcomings in their statistics and to confirm the applicability of the methodology followed in this study. New biomass and biofuels streams related to liquid biofuels will be challenging from the statistical standpoint, but they should, nevertheless, be taken into account in the compilation of statistics.

In Finland, import of raw biomass for biofuel production would enable considerably greater biofuel production than that considered in Paper II. BTL plants integrated with the forest industry have higher conversion efficiency than standalone BTL plants do; accordingly, their capacity to pay for raw material will be higher than that of separate BTL plants. Therefore, the options for import of biomass and integration of the BTL process with other heat loads, such as large district heating networks in coastal areas, are worthy of further investigation. The competitiveness and economics of second-generation biofuels are essential factors influencing the market penetration of biofuels. Optimal allocation of biomass resources among various end uses and optimisation of energy policy measures both are issues that deserve more research. It is recommended that similar wood stream studies be carried out in other countries, to confirm the applicability of the methodology followed in Paper II. An example is Russia, where the decrease in export of raw wood to Finland has resulted in a large surplus of forest biomass for second-generation biofuels.

Direct trade of solid and liquid biofuels is growing rapidly. In the past, the volume of indirectly traded biofuels was significantly higher – e.g., three times greater than the direct streams in 2004. This is a remarkable result, which has gained little attention so far. Methodological issues related to indirect trading of biofuels have to be explored in more detail in order to allow better insights into global biomass carbon flows. Yet it is clear that the amount of directly traded solid and liquid biofuels is increasing strongly, in some cases even exponentially in recent years. In the work on Paper III, it became clear that high-quality statistics on global bioenergy trade are often unavailable, and figures had to be indirectly estimated or based on expert opinions. As bioenergy trade is expected to increase strongly, reliable bioenergy trade figures are of use for industry actors, policymakers, and scientists alike, and, on account of bioenergy trade's expected pivotal role in the development of biomass production potential, increased efforts to collect and publish coherent energy biomass trade statistics are recommended.

Paper IV focused on free trade in biomass and bioenergy, and on the use of various criteria sets or schemes as means to promote sustainable production and utilisation in the global market. However, the majority of biomass and biofuels is used domestically. The efficiency of certification criteria and sustainability principles depends greatly on domestic consumers' interest in certified products. For example, Finnish consumers rely heavily on the sustainable management of their country's natural resources but there has been little demand for certified domestic forest products from the Finnish consumers. In such cases, domestic markets can and should be governed by legal and policy instruments, such as legislation, subsidies, taxes, and training. These instruments have been excluded from this study, but further study of these tools is recommended – particularly study of the effectiveness of policies and policy means in promoting sustainable production and utilisation, at both national and international level.

Paper V considered the future development of the international biomass market. A general conclusion drawn from the scenario analysis is that of the enormous opportunities related to the utilisation of biomass as a resource for global energy use in the coming decades. More research is needed for understanding future bioenergy evolution. The scenario analysis does, however, show the key issues in the field: global economic growth, including a growing need for energy; environmental forces in the global evolution; the possibilities of technological development for solving global problems; the capability of the international community to find resolutions for these global issues; and the complex interdependencies of the driving forces. Further research is needed here also, for analysis of the probabilities related to the technological and commercial aspects of each scenario as well as on what each scenario means in quantitative terms. For the practical use of the scenarios, it is also important to conceptualise the scale and directions of biomass trade streams and determine the influences of the scenarios with the aid of quantitative research from the viewpoints of different actors in the value network.

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9 References

Alakangas, E., Heikkinen, A., Lensu, T. & Vesterinen, P. 2007. Biomass fuel trade in Europe. Summary Report VTT-R-03508-07. Eubionet II - EIE/04/065/S07.38628. 55 p.

Beghin, J., Dong, F., Elobeid, A., Fabiosa, J., Fuller, F., Hart, C., Kovarik, K., Tokgoz, S., Yu, T.-H., Wailes, E., Chavez, E., Womack, A., Meyers, W., Binfield, J., Kruse, J., Madison, D., Meyer, S., Westhoff, P. & Wilox, L. 2007. U.S and World Agricultural Outlook. Food and Agricultural Policy Research Institute. Iowa State University and University of Missouri-Columbia. FAPRI Staff Report 07-FSR 1. ISSN 1534-4533. 395 p.

Berndes, G., Hoogwijk, M. & van den Broek, R. 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass and Bioenergy* 25 (1): 1-28.

Brown, M., Levine, M., Short, W. & Koomey, J. 2001. Scenarios for a clean energy future. *Energy Policy* 29 (14): 1179-1196.

Buchholz, T., Volk, T. & Luzadis, V. 2007. A participatory systems approach to modeling social, economic, and ecological components of bioenergy. *Energy Policy* 35 (12): 6084-6094.

Carriquiry, M., Dong, F., Elobeid, A., Fabiosa, J., Hart, C., Hayes, D., Kovarik, K., Ruan, J., Tokgoz, S., Yu, T.-H., Wailes, E., Chavez, E., Binfield, J., Brown, S., Madison, D., Meyer, S., Meyers, W., Thompson, W., Westhoff, P., Wilcox, L. & Womack, A. 2008. U.S and World Agricultural Outlook. Food and Agricultural Policy Research Institute. Iowa State University and the University of Missouri-Columbia. FAPRI Staff Report 08-FSR 1. ISSN 1534-4533. 395 p.

Confederation of European Paper Industries (CEPI). 2010. Preliminary Statistics 2009, European Pulp and Paper Industry. June. 2 p. Available at: http://www.cepi.org.

Dornburg, V., Faaij, A., Verweij, P., Langeveld, H., van de Ven, G., Wester, F., van Keulen, H., van Diepen, K., Meeusen, M., Banse, M., Ros, J., van Vuuren, D., van den Born, G.J., van Oorschot, M., Smout, F., van Vliet, J., Aiking, H., Londo, M., Mozaffarian, H. & Smekens, K. 2008. Biomass Assessment: Global biomass potentials and their links to food, water, biodiversity, energy demand and economy. Climate change scientific assessment and policy analysis (WAB) programme. 98 p.

Elghali, L., Clift, R., Sinclair, P., Panoutsou, C. & Bauen, A. 2007. Developing a sustainability framework for the assessment of bioenergy systems. *Energy Policy* 35 (12): 6075-6083.

Ericsson, K. & Nillsson, L.J. 2004. International biofuel trade - A study of the Swedish import. *Biomass and Bioenergy* 26 (3): 205-220.

Faaij, A., Junginger, M., Wagener, M., Weereld, A.V.d., Schouwenberg, P., Kwant, K., Hektor, B., Ling, E., Risnes, H., Klokk, S., Walter, A., Ranta, T., Heinimö, J., Bradley, D., Rosillo-Calle, F., Woods, J., Best, G., Utria, B., Grassi, A., Peksa, M. & Ryckmans, Y. 2005. Opportunities and Barriers for Sustainable International Bioenergy Trade: towards a Strategic Advice on IEA Task 40. 14th European Conference and Exhibition: Biomass for Energy, Industry and Climate Protection. 17-21 October 2005. Paris, France.

Faaij, A. & Domac, J. 2006. Emerging international bio-energy markets and opportunities for socio-economic development. *Energy for Sustainable Development* X. No. 1, March 2006: 7-19.

FAOSTAT data. 2009. From: http://faostat.fao.org/. Accessed 30 March.

FAOSTAT data. 2011. From: http://faostat.fao.org/. Accessed 17 October.

Finnish Forest Research Institute. 2009. "METINFO -database". From: http://www.metla.fi/metinfo. Accessed 4 June.

Finnish Forest Research Institute (METLA). 2009. Uutiskirje - Valtakunnan metsien inventointi (VMI). 1/2009. Available at: http://www.metla.fi/uutiskirje/vmi/2009-01/index.html.

Hakkila, P. 2004. Developing technology for large-scale production of forest chips. Wood Energy Technology Programme 1999 - 2003. Final report. Technology Report 5/2004. Tekes. 44 p. Available at: http://www.tekes.fi/english/programm/woodenergy.

Hansson, J., Berndes, G. & Börjesson, P. 2006. The prospects for large-scale import of biomass and biofuels into Sweden - a review of critical issues. *Energy for Sustainable Development* X. No. 1, March 2006: 82-94.

Heinimö, J. & Alakangas, E. 2009. Market of biomass fuels in Finland. IEA Bioenergy Task 40 and EUBIONET III - Country report of Finland 2009. Lappeenranta University of Technology. Faculty of Technology. Research report 3. ISBN 978-952-214-809-4. 35 p.

Heinimö, J. & Junginger, M. 2009. Production and trading of biomass for energy – an overview of the global status. *Biomass and Bioenergy* 33 (9): 1310–1320.

Hetemäki, L. 2009. Puu paperiksi vai energiaksi? Presentation at ´Kevätpäivä´ seminar of FINBIO. 22 May. Available at: http://www.metla.fi/hanke/50168/pdf/lauri_hetemaki_FINBIO_220409.pdf.

Hetemäki, L. & Hänninen, R. 2009. Arvio Suomen puunjalostuksen tuotannosta ja puunkäytöstä vuosina 2015 ja 2020. Working Papers of the Finnish Forest Research Institute 122. ISBN 978-951-40-2165-7. 63 p.

Hillring, B. 2006. World trade in forest products and wood fuel. *Biomass and Bioenergy* 30 (10): 815-825.

Hillring, B. & Trossero, M. 2006. International wood-fuel trade - an overview. *Energy for Sustainable Development* X No. 1, March 2006: 33-41.

Hoogwijk, M. 2004. On the global and regional potential of renewable energy sources. Doctoral dissertation, Copernicus Institute, Utrecht University. ISBN 90-393-3640-7. 256 p.

Hoogwijk, M., Faaij, A., Eickhout, B., de Vries, B. & Turkenburg, W. 2005. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. *Biomass and Bioenergy* 29 (4): 225-257.

IEA. 2008. World Energy Outlook 2008. Paris. ISBN 978-92-64-04560-6. 569 p. Available at: http://www.iea.org/textbase/nppdf/free/2008/weo2008.pdf.

IEA. 2010. Key World Energy Statistics. Paris. 78 p. Available at: http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf.

IEA. 2011. "Statistics & Balances

". From: http://www.iea.org/stats/index.asp. Accessed 26 March.

Indexmundi. 2007. "Oil; Palm - Production, Consumption, Exports, and Imports Statistics". From: http://www.indexmundi.com/en/commodities/agricultural/oil-palm/. Accessed 18 December.

IPCC (Intergovernmental Panel on Climate Change). 2000. Special Report on Emission Scenarios. Cambridge University Press. 570 p.

Joelsson, J., Gustavsson, L., Pingoud, K. & Soimakallio, S., 2009. CO_2 balance and oil use reduction of syngas-derived motor fuels co-produced in pulp and paper mills, 17th European Biomass Conference and Exhibition. ETA-Florence and WIP Renewable Energies, Hamburg, Germany, pp. 2252–2260.

Junginger, M. & Faaij, A. 2005. IEA Bioenergy task 40 - Country report for the Netherlands. Report NWS-E-2005-48. Universiteit Utrecht, Copernicus Institute. Department of Science technology and Society. July 2005. Utrecht. ISBN 90-73958-96-2. 27 p. Available at: http://www.bioenergytrade.org.

Junginger, M., Faaij, A., Rosillo-Calle, F. & Wood, J. 2006. The growing role of biofuels - opportunities, challenges and pitfalls. *International Sugar Journal* 108 (No 1295): 618-629.

Kaltschmitt, M. & Weber, M. 2006. Markets for solid biofuels within the EU-15. *Biomass and Bioenergy* 30 (11): 897-907.

Krotscheck, C., König, F. & Obernberger, I. 2000. Ecological assessment of integrated bioenergy systems using the Sustainable Process Index. *Biomass and Bioenergy* 18 (4): 341-368.

Kärhä, K., Elo, J., Lahtinen, P. & Räsänen, T. 2009. Puupolttoaineiden saatavuus ja käyttö Suomessa 2020 [´Availability and use of wood-based fuels in Finland in 2020´]. Metsäteho Oy & Pöyry Energy Oy. Metsätehon tuloskalvosarja 9/2009. 59 p. Available at: http://www.metsateho.fi/files/metsateho/Tuloskalvosarja/Tuloskalvosarja_2009_09_Puupolttoaineiden_saatavuus_ja_kaytto_kk.pdf.

Lensink, S. & Londo, M. 2010. Assessment of biofuels supporting policies using the BioTrans model. *Biomass and Bioenergy* 34 (2): 218–228.

Lewandowski, I. & Faaij, A.P. 2006. Steps towards the development of a certification system for sustainable bio-energy trade. *Biomass and Bioenergy* 30 (2): 83-104.

Londo, M., Lensink, S., Deurwaarder, E., Wakker, A., de wit, M., Junginger, M., Könighofer, K. & Jungmeier, G. 2008. Biofuels cost developments in the EU27+ until 2030. Full-chain cost assessment and implications of policy options. Refuel WP4 final report. 47 p. Available at: http://www.refuel.eu/fileadmin/refuel/user/docs/REFUEL_D11_WP4_report-fixed.pdf.

McKeough, P. & Kurkela, E., 2007. Detailed comparison of efficiencies and costs of producing FT liquids, methanol, SNG and hydrogen from biomass, 15th European Biomass Conference & Exhibition, Berlin, Germany, pp. 1161-1166.

McKeough, P. & Kurkela, E. 2008. Process evaluations and design studies in the UCG project 2004 - 2007. VTT Research Notes 2434. ISBN 978-951-38-7210-6. 45 p.

Ministry of Employment and the Economy. 2008. Pitkän aikavälin ilmasto- ja energiastrategia [´Long-term Climate and Energy Strategy´]. Helsinki. 130 p. Available at: http://www.tem.fi/index.phtml?s=2542.

Mäkinen, T., Soimakallio, S., Paappanen, T., Pahkala, K. & Mikkola, H. 2006. Liikenteen biopolttoaineiden ja peltoenergian kasvihuonekaasutaseet ja uudet liiketoimintakonseptit. VTT Research Notes 2357. ISBN 951-38-6826-5. 134 p.

Obernberger, I. & Thek, G. 2010. The Pellet Handbook - The production and thermal utilisation of biomass pellets. Earthscan. ISBN 978-1-84407-631-4. 549 p.

Pekkarinen, M. 2010. Kohti vähäpäästöistä Suomea - Uusiutuvan energian velvoitepaketti. Power Point presentation. 20 April. Ministry of Employment and the Economy. Helsinki. Available at: http://www.tem.fi/files/26643/UE_lo_velvoitepaketti_Kesaranta_200410.pdf.

Peltola, A. (ed.). 2008. Metsätilastollinen vuosikirja 2008 [´The Finnish Statistical Yearbook of Forestry 2008´]. Finnish Forest Research Institute. ISBN 978-951-40-2131-9. 456 p.

Peltola, A. (ed.). 2009. Metsätilastollinen vuosikirja 2009 [´The Finnish Statistical Yearbook of Forestry 2009´]. Finnish Forest Research Institute. ISBN 978-951-40-2204-3. 450 p.

Port of Rotterdam. 2008. "Verdubbeling Rotterdamse Overslag Biobrandstoffen (doubling of liquid biofuels trade in Rotterdam harbour)". From: http://www.portofrotterdam.com/nl/nieuws/persberichten/2008/20080229_01.jsp. Accessed 29 February.

Ranta, T. 2005. Logging residues from regeneration fellings for biofuel production-A GIS-based availability analysis in Finland. *Biomass and Bioenergy* 28 (2): 172-182.

Reini, K., Törmä, H. & Mäkinen, J. 2010. Massa- ja paperiteollisuuden supistumisen ja tulevaisuuden kuvien aluetaloudelliset vaikutukset. Helsingin yliopisto (University of Helsinki). Ruralia instituutti. Raportteja 50. ISBN 978-952-10-5414-3. 37 p.

Renewable Fuels Association. 2009. "Ethanol Industry Statistics". From: http://www.ethanolrfa.org/industry/statistics/#E. Accessed 29 March.

Rosillo-Calle, F. & Walter, A. 2006. Global Market for Bioethanol: historical trends and future prospects. *Energy for Sustainable Development* X. No. 1, March 2006: 20-32.

Rotmans, J., van Asselt, M., Anastasi, C., Greeuw, S., Mellors, J., Peters, S., Rothman, D. & Rijkens, N. 2000. Visions for a Sustainable Europe. *Futures* 32 (9-10): 809-831.

Schoemaker, P. 1991. When and How to Use Scenario Planning: A Heuristic Approach with Illustration. *Journal of Forecasting* 10 (6): 549-564.

Shell. 2005. Executive Summary of the Shell Global Scenarios to 2025. 18 p. Available at: http://www.shell.com/static/royal-en/downloads/scenarios/exsum_23052005.pdf.

Sikkema, R., Junginger, M. & Faaij, A. 2008. Proceedings of the workshop on Development of meaningful statistics for sustainable bioenergy trade, organized by IEA Bioenergy Task 40 on Sustainable International Bio-energy Trade. 25 February. Paris, France. 9 p. Available at: http://www.bioenergytrade.org/downloads/parisproceedingsworkshopmeaningfulbioenergytra.pdf.

Sipilä, E., Jokinen, J., Sipilä, K. & Helynen, S., 2009a. Bioenergy market potential in European forest industry to 2G biofuels and CHP power production by 2020, 17th European Biomass Conference and Exhibition. ETA-Florence and WIP Renewable Energies, Hamburg, Germany, pp. 2084–2092.

Sipilä, E., Vehlow, J., Vainikka, P., Wilén, C. & Sipilä, K. 2009b. Market potential of high efficiency CHP and waste based ethanol in European pulp and paper industry. VTT Research Notes 2500. ISBN 978-951-38-7320-2. 73 p. Available at: http://www.vtt.fi/publications/index.jsp.

Smeets, E., Faaij, A. & Lewandowski, I. 2004. A quickscan of global bio-energy potentials to 2050. An analysis of the regional availability of biomass resources for export in relation to the underlying factors. Copernicus institute - Utrecht University. ISBN 90-393-3909-0. 121 p.

Smeets, E., Faaij, A., Lewandowski, I. & Turkenburg, W. 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science* 33 (1): 56-106.

Statistics Finland. 2009. Energy Statistics. Yearbook 2008. Official statistics of Finland. Helsinki. ISBN 978-952-467-996-1.

Stupak, I., Asikainen, A., Jonsell, M., Karltun, E., Lunnan, A., Mizaraitė, D., Pasanen, K., Pärn, H., Raulund-Rasmussen, K., Röser, D., Schroeder, M., Varnagirytė, I., Vilkriste, L., Callesen, I., Clarke, N., Gaitnieks, T., Ingerslev, M., Mandre, M., Ozolincius, R. & Saarsalmi, A. 2007. Sustainable utilisation of forest biomass for energy—Possibilities and problems: Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. *Biomass and Bioenergy* 31 (10): 666-684.

The European Parliament and the Council. 2009. Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 23 April. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF.

Torvelainen, J. 2009. Pientalojen polttopuun käyttö 2007/2008 ['Use of firewood in single-family houses']. Finnish Forest Research Institute. Metsätilastotiedote 26/2009. 4 p.

United States Department of Agriculture. 2009. "Production, Supply and Distribution Online". From: http://www.fas.usda.gov/psdonline/. Accessed 29 March.

Walter, A., Rosillo-Calle, F., Dolzan, P., Piacente, E. & Borges da Cunha, K. 2008. Perspectives on fuel ethanol consumption and trade. *Biomass and Bioenergy* 32 (8): 730-748.

van Dam, J., Junginger, M., Faaij, A., Jürgens, I., Best, G. & Fritsche, U. 2008. Overview of recent developments in sustainable biomass certification. *Biomass and Bioenergy* 32 (8): 749-780.

Vesterinen, P. & Alakangas, E. 2001. Export & import possibilities and fuel prices of biomass in 20 European countries - Task 2. ALTENER Programme. AFB-net V. 45 p.

Ylitalo, E. (ed.). 2008. Puun energiakäyttö 2007. Metsätilastotiedote 15/2008. 7.5.2008. Official Statistics of Finland. Helsinki. 5 p.

Zarrilli, S. 2006. The Emerging Biofuels Market: regulatory, trade and development implications. United Nations Conference on Trade and Development. Geneva, Switzerland. 52 p. Available at: http://www.unctad.org/en/docs/ditcted20064_en.pdf.

Zarrilli, S. 2008. Making certification work for sustainable development: the case of biofuels. UNCTAD biofuels initiative. New York / Geneva. 48 p. Available at: http://www.unctad.org/en/docs/ditcted20081_en.pdf.

Äijälä, O., Kuusinen, M. & Koistinen, A. 2010. Hyvän metsänhoidon suositukset energiapuun korjuuseen ja kasvatukseen. Metsätalouden kehittämiskeskus Tapion julkaisuja. 31 p. Available at: http://www.tapio.fi/verkkojulkaisut.

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