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Riitta Hänninen
Lauri Hetemäki
Elias Hurmekoski
Antti Mutanen
Annukka Näyhä
Juha Forsström
Jari Viitanen
Tiina Koljonen

European Forest Industry and Forest Bioenergy Outlook up to 2050: A Synthesis

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Sustainable Bioenergy
Solutions for Tomorrow

Cleen Oy
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Preface

This report is a part of the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program coordinated by FIBIC Ltd, and CLEEN Ltd. with funding from the Finnish Funding Agency for Technology and Innovation, Tekes.

The report in hand belongs to BEST research program's Working Package 1 (WP1) "Bioenergy Scenarios and Strategies in Global and Local Scales", and its Task 1.1 "Critical Synthesis of Existing Bioenergy Scenarios 2010–2050" and Subtask 1.1.1 "Critical Synthesis of Model Studies". The purpose of this report is to give a critical literature review of some of the most relevant and mainstream scenario analyses concerning the use and assessments of biomass in industry and energy sectors, and its development up to 2050. The main focus is in forest biomass but also the field and other potential bioenergy raw materials are highlighted. The outcomes and observations of this report can be utilised in further model building and reassessment scenarios of forest bioenergy use.

The authors are professionals and experts in forest economics and forest bioenergy representing Finnish Forest Research Institute (Riitta Hänninen, Antti Mutanen and Jari Viitanen), European Forest Institute (Lauri Hetemäki, Elias Hurmekoski), University of Eastern Finland (Annukka Näyhä) and VTT Technical Research Centre of Finland (Juha Forsström and Tiina Koljonen).

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Summary

The use of bioenergy is expected to grow in future. For example, the EU has set ambitious strategies and targets for promoting bioenergy and other renewables. The expected growing demand has raised the question, whether biomass can be procured sufficiently and sustainably. The availability, future demand for, and supply of bioenergy have been addressed in several reports and studies with differing scopes, assumptions, and modelling techniques.

The present report aims to construct a systematic and critical review of the existing scenarios for the demand for and supply of biomass for energy production. The focus is on forest bioenergy and on identifying the major gaps in knowledge and needs for further assessments.

The main drivers of future demand for bioenergy are the policy measure related to climate change mitigation and energy security. For example in Europe, the EU 20-20-20 targets are impacting the demand for forest and other biobased energy until 2020 and beyond. According to the Member State's National Renewable Energy Plans bioenergy is the major contributor to reach the renewable 2020 energy targets. The widely cited EUwood study suggests a shortage of forest biomass within the EU until 2030, when the EU targets are assumed to be fulfilled and forest industry production continues the historical growth trend. This result has been criticised in later studies, and it seems necessary to discuss further the reasons for differencing estimates provided in the studies.

The future supply of forest bioenergy is closely linked with forest industry due to the synergies between forest products and bioenergy production. However, the links and impacts of pulp and paper industry on one hand, and the wood products industry on the other hand, on the forest bioenergy potential differ to some extent.

The decline in the paper industry's production especially in Western Europe will reduce the future demand for pulp and pulpwood in Europe as a whole, but the net effect of this development on European bioenergy production would need a profound research. However, it is clear, that the companies operating in bioenergy related business should be prepared for the possibility of the declining European pulp production and its impacts to forest bioenergy outlook. For further research, interesting questions are also the outlooks for dissolving pulp and pulp mill based energy production in Europe.

The volume of sawlog removals determines to a significant extent the supply and availability of both industrial residues and forest residues for forest bioenergy production. Therefore, the critical issues in wood products markets in terms of

bioenergy potential culminate to the volume of sawnwood markets, the indirect multiplier effects of sawlog harvesting, and the emerging possibilities to integrate bioenergy production to sawnwood production. For future sawnwood demand, the reviewed outlook studies indicate a rather stagnated growth in Europe. However, the reviewed studies do not take into account the possible structural changes that could strongly decrease or increase the use of wood, for example, in construction, in future.

Although forest biorefineries (i.e. 2nd and 3rd generation biofuel production and high value-added products) are often considered a new business opportunity, information related to current development, future prospects, and challenges is scarce and scattered. For example, more information is needed about how to choose the most promising business portfolios (i.e. services/high value-added products/large-scale manufacturing) and what policies would be effective. Important information needs are also related to the sustainability, availability, and price of forest-based biomass.

Several studies have focused on scrutinising the amount of woody biomass that could be harvested for energy production, but different assessments and scenarios leaves the reader puzzled. Comparison of the results of different studies is challenging due to varying definitions, constraints, assumptions, biomass types, time horizons, approaches, and methodologies employed. Thus, direct comparison of point estimates between the studies is in many cases inadvisable, and insight into the procedures by which the estimates were obtained and the related uncertainties is needed in order to avoid misleading conclusion.

A few important topics are not addressed as adequately as one would expect in the existing forest bioenergy assessments and scenarios. For example, the role of new, innovative products or the carbon neutrality of wood in energy production is hardly considered. The changes in policies related to bioenergy subsidies or biodiversity and water protection create uncertainties in the supply of biomass for bioenergy. The possibility of increasing forest biomass trade would have important impacts on the markets. Demand for wood based energy is affected by the policy targets and prices of competing energy sources. Overall, the general acceptability and competitiveness of wood and other biobased raw materials in energy and biofuel production should be discussed more elaborately, as these issues are surely defining the future of forest bioenergy.

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Contents

1. Introduction

Renewable energy and it's environmentally, economically, and socially sustainable production and use are amongst the most important factors affecting the prosperity and wellbeing of the humankind in the near future. Along with the population growth, urbanisation, and increasing standard of living, the global energy consumption is estimated to grow significantly during the following decades. In order to decrease the global dependency on fossil fuels and to mitigate greenhouse gas emissions, renewable energy sources are often seen as the main solution. Thus, the main drivers of future demand for renewable energy are the policy targets and related measures aiming at greenhouse gas mitigation and improving energy security.

Currently, about 13 percent of world's primary energy consumption is based on renewable sources, and of the consumption of renewable energy, 80 percent rests upon biomass. According to speeches and political declarations, the role of bioenergy is envisaged to be enhanced in many regions in future. Bioenergy is produced from wide variety of feedstocks of biological origin and by numerous conversion technologies to produce heat, power, liquid biofuels, and gaseous biofuels. The "traditional domestic" use of fuelwood, charcoal, and agricultural residues in developing countries for household cooking, lighting and space-heating is the dominant source of world's bioenergy. The industrial use of biomass for production of pulp, paper, tobacco, pig iron, etc. produces side streams (i.e. bark, wood chips, black liquor, agricultural residues, etc.), which may be converted to bioenergy. Chemical conversion technologies (i.e. Fisher-Tropsh synthesis and other chemical routes) are used to produce liquid and gaseous fuels, and biological conversion technologies to produce biogas (i.e. anaerobic digestion) and alcohols (i.e. fermentation). In the long term, also bio-photochemical routes (i.e. algae, hydrogen, etc.) may offer new bioenergy resources.

According to the IEA Statistics, the share of bioenergy has been about 10 percent of global Total Primary Energy Supply (TPES) since 1990 even though TPES has been increasing at an average annual rate of 2.0 percent. Between 1990 and 2010 bioenergy supply has increased from 38 to 52 EJ as a result of increasing energy demand in non-OECD countries and, on the other hand, new policies to increase the share of renewable and indigenous energy sources especially in many OECD and but also in non-OECD-countries. Solid biofuels, mainly wood, are the largest renewable energy source, representing 69 percent of world renewable energy supply. Solid biofuels are mainly used in developing countries, especially in South Asia and sub-saharan Africa. Liquid biofuels for transport provide about 4 percent of world renewable energy supply and 0.5 percent of global TPES. The share of biogases in world renewable energy supply is only 1.5 percent but it had the highest growth rate since 1990 (about 15 percent per year) compared to other biofuels. Liquid biofuels also had remarkable growth rate (11 percent per year) while the growth rate of solid biofuels was moderate (1percent per year) (IEA 2012).

In 2010, the largest bioenergy producers were China and India, who produced 20 percent and 17 percent of the world's bioenergy respectively (IEA 2012). In China, the share of bioenergy is less than 10 percent of its TPES while in India it is almost 25 percent. In the third and fourth largest bioenergy producers, Nigeria and United States, the share of bioenergy of TPES was above 80 percent and below 4 percent respectively in 2010, which clearly shows the difference between developing and industrialized countries: in developing non-OECD countries bioenergy is typically the major energy source while in the OECD-countries bioenergy typically covers minor share of TPES.

In future, the use of bioenergy, especially the use of so called modern bioenergy, is projected to grow, and for example, in the EU, ambitious targets on the use of bioenergy have been set. The expected growing demand for bioenergy has raised the question, whether biomass can be procured from forests sufficiently and sustainably. However, despite the growing demand for bioenergy, its share of the global TPES, is not expected to grow substantially. The reason is that the total energy consumption is projected to grow at the same or even at higher rate than the use of bioenergy.

The future availability of bioenergy is closely related to the question of land availability for biomass production for different uses, as well as how economical it is to exploit the biomass available. However, as on one hand, energy use of biomass can be considered competing with, for example, food production, on the other hand, energy use of biomass may offer new markets for those fractions that were earlier regarded as waste, and hence it benefits and complements conventional forms of biomass production and use. Thus, production and use of bioenergy interacts with food, fodder and fibre production as well as with conventional forest products in complex ways.

The literature on the assessment of biomass[1] in energy production is abundant. However, the estimates of future bioenergy availability, supply, and demand vary remarkably. For example, depending on the study, the global potential deployment levels of biomass for energy by 2050 range from 50 to 300 EJ/a. Obviously, the direct comparison of estimates for future availability, supply of, or demand for bioenergy is challenging, due to the different definitions, concepts, and methods applied.

In this study, the focus is on forest bioenergy, the future availability of which depends on the other uses of forest biomass and functions of forests, such as raw material for industry, biodiversity protection, carbon store, recreation, landscape, social sustainability, etc. Especially, the future availability of forest bioenergy is closely related to the forest industry

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[1] In literature, biomass in energy production is defined in many different ways, e.g. *traditional biomass, modern biomass, highly efficient bioenergy,* etc. which makes it difficult to compare future demand and supply scenarios between the different literature sources. The definitions are discussed in more detail in Chapter 4.

production, due to the potential synergies between forest products and bioenergy production. Thus, in the assessment of future forest bioenergy potential or demand, several factors and their possible development have to be considered, which in turn, increases variation and uncertainty of the estimates.

This study provides a systematic and critical review of existing forest bioenergy assessments and scenarios. The aim is to give the reader insight into the most important factors affecting supply of and demand for forest bioenergy and the procedures by which the assessments and scenarios of forest bioenergy are created. The issue of differencing terms, assumptions, approaches, and methodology as well as sources of uncertainty related to the estimates are also discussed. Critical questions and important issues that have not received enough attention in forest bioenergy assessments and more widely in forest sector outlooks are pointed out. The regional focus of the present study is in the Europe, but also global issues are also considered.

The study is organised as follows. As the demand for forest bioenergy, and energy in general, as well as the consumption of forest industry products are closely related to economic development, Chapter 2 shortly summarises the recent GDP and population growth projections together with demographic changes up to 2050, and compares how these projections differ from those made before the global economic slowdown in 2008. Chapter 3 summarises the linkages between forest products markets and forest bioenergy with the implications to the existing bioenergy system projections. In Chapter 4, demand and supply scenarios of forest bioenergy in Europe, North America, and Russia are summarised and evaluated. Differences and possible weaknesses of the assessments and scenarios, such as definitions, underlying assumptions, missing factors, and the role of uncertainty, are discussed. Finally, Chapter 5 presents the synthesis and conclusions of the study.

2. Global Economic Outlook

According to the OECD (2012) and PwC Economics (2013), the world economy as total is assessed to grow about 3 percent on an average per annum up to 2050 as measured by Gross Domestic Product (GDP). The Conference Board (2013) projects emerging and developing countries[2] to grow at 3.2 percent annually during the time period 2020–2025. The global growth, however, is distributed rather unevenly between continents, regions, and individual countries. As depicted in Table 2.1, the main projection is that in the emerging economies, such as in China, India, Brazil, South Africa, and Indonesia some to mention, the economic growth over the next decades is much faster than in G7 countries. PwC Economics (2013) estimates that for the oncoming decades the annual average growth rate for emerging economies is about 4 percent while advanced economies tend to grow at about 2 percent or even less. The OECD (2012), on the other hand, projects that the average annual growth rate for the non-OECD countries will be around 5 percent with respect to around 2 percent trend growth in the OECD countries. When comparing the continents, Asia, Latin, and Mid-America as well as Africa to some extent are the areas which are growing fastest. Europe is assessed to regress as a slow growth region and gradually to lose its relative relevance in the world economy. The USA is evaluated to maintain its strong position also during the oncoming decades.

Technically, the faster economic growth in emerging countries with respect to standard industrialised countries means an economic convergence across the countries and regions. It should be noted, however, that in general, the annual average economic growth as measured by GDP is gradually assessed to decline both in emerging and industrial countries over the oncoming decades.

Despite the economic convergence between the countries and regions measured by GDP growth, the OECD (2012) emphasises that the large cross-country differences in living standards still persist in 2060. In the poorest economies, the income per capita may quadruple and in China and India, even become sevenfold. Still, the living standards in these countries as well as in other emerging economies can be only 25–60 percent of the level of the leading countries. The Russian Federation is an exception and essentially can catch up the poorer G7 economies in terms of per capita income by 2050.

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[2] The terminology is rich and sometimes confusing. In general, *emerging economies or markets* means areas or nations where the economic outcome (typically measured by GDP or GDP/capita) has been low, and the business activity and industrialisation is in the process of rapid growth. *Industrialised, mature, developed and advanced economies or markets* are areas or nations where the industrialisation has started decades or even centuries ago and where economic growth has been strong. *BRIC-countries* are Brazil, Russia, India and China. *BRICS-countries* include also South Africa. *MINT-countries* are Mexico, Indonesia, Nigeria and Turkey. *G7 countries* are the USA, the UK, Germany, France, Italy, Canada and Japan (*G6 countries* consist of G7 without Canada) while *E7 countries* refers to China, India, Brazil, Russia, Indonesia, Mexico and Turkey. *CIVETS- countries* include Columbia, Indonesia, Vietnam, Egypt, Turkey and South Africa. *Next 11 group (N-11)* consists of Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, Philippines, Vietnam and Turkey.

Table 2.1 Average Annual Growth Rate of GDP in Some Selected Countries.

	1985–2011	2011–2030	2030–2060	2011–2060
Argentina	3.6	3.6	2.2	2.7
Australia	3.3	3.1	2.2	2.6
Brazil	3.3	4.1	2.0	2.8
Canada	2.6	2.1	2.3	2.2
China	10.0	6.6	2.3	4.0
Finland	2.5	2.1	1.6	1.8
France	1.7	2.0	1.4	1.6
Germany	1.4	1.3	1.0	1.1
Indonesia	4.4	5.3	3.4	4.1
India	7.5	6.7	4.0	5.1
Italy	1.0	1.3	1.5	1.4
Japan	0.9	1.2	1.4	1.3
Korea	4.6	2.7	1.0	1.6
Mexico	2.6	3.4	2.7	3.0
Netherlands	2.2	1.8	1.6	1.7
Poland	4.3	2.6	1.0	1.6
Russia	5.1	3.0	1.3	1.9
Spain	2.9	2.0	1.4	1.7
South Africa	3.4	3.9	2.5	3.0
Sweden	2.5	2.4	1.8	2.0
Turkey	4.2	4.5	1.9	2.9
United Kingdom	2.3	1.9	2.2	2.1
United States	2.5	2.3	2.0	2.1

The figures are evaluated as USD 2005 PPPs. Source: OECD (2012).

As the development of bioenergy use, demand, and supply are highly dependent on national level as well as global economic activity, among others, it is fertile to shortly

review, how the projections of the economic growth rates in different areas have changed over time. Especially, it is interesting to find out whether the projections and forecasts before the beginning of the global economic crises and recession in 2008 differ substantially from the most recent estimates when there are already some budding signs of recovery of economies. While the estimates for GDP growth in Intergovernmental Panel on Climate Change (IPCC) special reports of emissions scenarios (SRES) are most cited also in other bioenergy calculations and scenarios, it is also of special interest to find out whether these estimates are out-of-date and if they require reassessment and updating. Thus, technically the comparison reveals if the economic activity after the recession is estimated to recover back to its average trend growth rate or whether the slopes of trend growth of economic regions or individual countries are reassessed.

When comparing the most recent projections of economic growth rates with respect to those made before the recession and IPCC scenarios, the main findings can be summarised as follows. First, the comparison is not straightforward and the figures are even somewhat contradictory[3] as can be seen in Tables 2.2–2.4. The general observation, however, is that the projections concerning the growth for some traditional industrialised countries before the beginning of the economic slowdown in 2008 were slightly more positive with respect to reassessments after 2008 (see also Table 2.1). Similar inference can be drawn when comparing the recent projections with respect to those of IPCC's assumptions[4], even though the GDP growth assumptions themselves vary between the different SRES scenarios.

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[3] Technically, the direct comparison of the different studies is difficult. The time spans typically differ substantially between the studies and the studied regions are not directly comparable. In some studies, the projected average annual growth rates, for example, consist of the whole Asia, while in other studies, the projections concern only industrialised Asia and the difference between these projections can be as much as several percentage points. Typically, most of the studied are concentrating on the BRICS countries, emerging markets or individual countries. Similar difficulties are encountered later in Chapter 4, when comparing the assumptions and outcomes of the recent forest bioenergy scenarios.

[4] With a few exceptions, the IPCC does not give separate growth estimates for individual countries. Rather, the projections are given for large economic regions such as developing Asia. The GDP growth estimates for individual countries within the regions have all the same value.

Table 2.2 Average Annual Growth Rates of GDP Used by IPCC's SRES Calculations.

	1990–2030				1990–2050			
	A1	A2	B1	B2	A1	A2	B1	B2
OECD90	2.1	1.7	2.1	1.8	2.0	1.6	1.9	1.4
EU27	2.2	1.7	2.1	1.7	2.1	1.6	1.9	1.4
REF	4.1	2.1	2.7	2.4	4.1	2.3	3.1	3.0
IND					2.2	1.6	1.9	1.6
ASIA	7.3	4.4	6.1	6.8	6.3	4.0	5.6	5.7
ALM	6.0	4.1	5.4	3.9	5.6	3.8	5.2	4.2
DEV					5.9	3.8	5.2	4.9
WORLD	3.6	2.4	3.2	2.9	3.6	2.3	3.2	2.8
United States	2.4	2.0	2.3	2.1	2.2	1.9	2.0	1.8
China	8.7	4.8	5.9	8.2	7.2	4.3	5.3	6.5
India	6.5	4.2	6.8	5.0	5.9	3.9	6.5	5.3
Japan	1.7	1.4	2.0	1.3	1.7	1.2	1.7	1.0
Germany	2.1	1.7	2.1	1.7	2.0	1.6	1.8	1.3
UK	2.1	1.7	2.1	1.7	2.0	1.6	1.8	1.3
Italy	2.1	1.7	2.1	1.7	2.0	1.6	1.8	1.3
Turkey	2.1	1.7	5.1	1.7	2.0	1.6	4.9	1.3
France	2.1	1.7	2.1	1.7	2.0	1.6	1.8	1.3
Russia	4.1	2.1	2.4	2.2	4.1	2.3	3.1	3.0
Indonesia	6.5	4.2	5.7	6.3	5.9	3.9	5.0	5.0
South Korea	6.5	4.2	5.7	6.3	5.9	3.9	5.0	5.0
Argentina	6.1	3.7	5.1	3.9	5.1	3.4	4.6	3.9
Brazil	6.1	3.7	5.1	3.9	5.1	3.4	4.6	3.9
Vietnam	8.7	4.8	5.9	8.2	7.2	4.3	5.3	6.5
Mexico	6.1	3.7	5.1	3.9	5.1	3.4	4.6	3.9

OECD90 region groups together all member countries of the Organization for Economic Cooperation and Development as of 1990, **REF** region consists of countries undergoing economic reform and groups together the East and Central European countries and the Newly Independent States of the former Soviet Union, **ASIA** region stands for all developing countries in Asia (excluding the Middle East), **ALM** region stands for the rest of the world and corresponds to developing countries in Africa, Latin America, and Middle East. OECD90 and REF regions together roughly correspond to industrialised (developed) countries (**IND**), while the ASIA and ALM regions together roughly correspond to the developing countries (**DEV**). Source: Gaffin et al. (2002).

Table 2.3 Projected Average Annual Growth Rates of GDP for Individual Countries before the Economic Recession in 2008.

	EIU (2006)	CEPII (2006)	PwC (2008)	OECD (2009)	OECD (2009)
	2006–2020	2005–2050	2007–2050	2006–2025	2025–2050
United States	2.9	2.8	2.4	2.4	2.2
China	6.0	5.4	4.7	6.6	3.2
India	5.9	4.8	5.8	7.6	5.6
Japan	0.7	1.7	1.5	1.5	0.8
Germany	1.9	2.0	1.6		
UK	2.3	2.4	2.3		
Italy	1.0	1.5	1.9		
Turkey	4.4	2.3	4.1		
France	1.9	1.8	2.3		
Russia	3.3	4.1	2.5	3.4	1.8
Indonesia	5.2	5.1	4.5		
South Korea	4.0	4.9	2.2		
Argentina	3.6	2.4			
Brazil	3.2	1.4	3.8	4.0	3.9
Vietnam	5.4				
Mexico	2.9	2.4	3.7		

EIU (2006), CEPII (2006) and OECD (2009) refer to the reports by The Economist Intelligence Unit (2006), Poncet (2006) and Duval and Maisonneuve (2009), respectively.

Even though the conclusion is again not unambiguously, the recent forecasts concerning the annual growth of GDP in Table 2.1 seem slightly revised downwards with respect to those in the IPCC scenarios. In other words, the forecasts have converged towards the IPCC's most pessimistic scenarios. For example, the estimates for Latin America, China, and the majority of European countries are lower in the OECD's (2012) report than in the IPCC's scenarios, whereas the recent estimates for the USA and India are roughly in line with the IPCC scenarios. The estimates in Table 2.3 just before the economic slowdown confirm the view of reassessments of GDP growth after the worldwide debt crises. For

example, the annual growth rate estimates for the USA, the Russian Federation, the UK, and other Western European countries are typically evaluated as slower. In contrast, the studies after 2008 typically projects BRICS and MINT countries and industrialised Asia to grow slightly faster with respect to assessments before the start of recession. Second, studies both before and after 2008 project that the worldwide economic growth is gradually slowing until 2050. Third, the projections of the relative and rank position of the economic regions and countries after 2030 have not changed substantially over time.

Table 2.4 Projected Average Annual Growth Rates of GDP before and after the Economic Recession in 2008.

Projections before the Economic Crises in 2008

	EIU (2006)	CEPII (2006)	OECD (2009)	OECD (2009)
	2006–2020	2005–2050	2006–2025	2025–2050
World	3.5	2.6	3.2	3.0
EU15	2.0			
EU25/EU27	2.1	1.9	2.4	1.7
Asia	4.9			
Latin America	3.2	1.4		
M. East/N. Afr.	4.0			

Projections after the Economic Crises in 2008

	HSBC (2012)	IMF (2013)	CB (2013)	PwC (2013)
	2010–2050	2015–2018	2020–2025	2012–2050
World	1.9*	5.4**	2.4	3.1
EU15			1.2	
EU25/EU27			1.3	
Asia	5,0	6.7***		
Latin America	4.3	3.7	2.9	
M. East/N. Afr.	3,8	4.2	2.3/4.1	

CB (2013) refers to the report by The Conference Board (2013). * denotes to developed countries while ** refers to emerging and developing economies and *** refers to developing Asia.

The main determinants and drivers behind the economic growth are *demographic changes* and *growth of population*, *technical progress and structural changes in labour markets*, *migration* and *human capital* together with *level of education*. Also, the adapted national or union level *policies* are likely to affect prospects for economic growth.

Table 2.5 Population of the World in 1980, 2013 and 2050, Billions of Inhabitants.

Area	1980	2013	2050
World	4.449	7.162	9.551
More developed regions	1.083	1.253	1.303
Less developed regions	3.366	5.909	8.248
Least developed countries	0.393	0.898	1.811
Other less developed countries	2.973	5.011	6.437
Africa	0.478	1.111	2.393
Asia	2.634	4.299	5.164
Europe	0.695	0.742	0.709
Latin America and Caribbean	0.364	0.617	0.782
Northern America	0.255	0.355	0.446
Oceania	0.023	0.038	0.057

Source: United Nations (2013). The figures present the medium-variant projections of UN scenarios.

The growth of population and demographic changes are particularly important determinants for economic growth. First, the amount of population is closely related to demand and consumption, which are essential fundaments of the GDP. In industrialised countries, private consumption typically accounts for about half of GDP. In the USA, the share is as much as 70 percent, while in emerging economies the share is considerably lower than half of the GDP. In China, the share of private consumption is only about one third of the GDP. Second, the demographic changes are highly related to the share of working-age population as well as the structure of consumption (senior citizens and young cohorts typically demand for different kinds of consumption goods and services).

Over the next forty years, the global labour force will grow rapidly, but it is estimated to distribute rather unevenly in the world. According to the United Nations (2013) recent report, the world population of 7.2 billion in July 2013 is projected to increase to 8.1 billion in 2025 and further to 9.6 billion by 2050. As shown in Table 2.5, the population will grow especially in developing countries.[5] In Europe, the number of inhabitants is expected to decrease slightly. The USA is an exception among advanced economies, as the population is still growing until 2050. By 2030, the population of India is assessed to surpass that of China and together these two counties will account for about 35 percent of the whole world population.

The demographic change - the declining fertility rate and increasing life expectancy - has significant effect on economic growth as it leads to declining share of the working age population (15–64 years) which can be either supported by immigration or embedded by emigration. The OECD (2012) assesses that ageing over 50 years will be particularly rapid in Asia, Eastern Europe, and Southern European countries with old-age dependency ratios more than doubling, and even quadrupling in China. In parallel, the share of the working-age population in most countries is projected to decline over the half century building up pressure to finance the pension system, among others. However, there are some exceptions such as South Africa and India which will experience an increase in their shares of working-age population. Typically, in most countries the effect of net migration is not sufficient to offset the consequences of population ageing on the labour force.

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[5] More detailed projections by countries can be found in United Nations (2013) report. Also, the World Bank gives detailed figures concerning individual countries and areas in their web page http://go.worldbank.org/KZHE1CQFA0

3. Forest Industry Market Outlook

3.1 Background

Forest products markets play in many ways a central role in the forest biomass supply for bioenergy purposes. Therefore, when assessing the potential future biomass supply for bioenergy production, it is essential also to provide an outlook for forest industry and its markets, and the implications of this to biomass supply to bioenergy purposes.

The links and impacts of pulp and paper industry on the one hand, and the wood products industry on the other hand, to the forest biomass potential for bioenergy purpose, differ to some extent. As a result, it is useful to address these industry sectors separately. In the Table 3.1 below, we have summarised some of major channels through which the forest products markets may impact the forest biomass markets for bioenergy purposes.

Table 3.1 The Interaction between Forest Products Markets and Forest Biomass.

Sector	Impact
Pulp and paper	Changes in the volume of pulp production impact the *demand* and *prices* of forest biomass (roundwood, chips, forest residues, tal oil, black liquore) that can be used also for bioenergy production
	Forest residues that end up to bioenergy production are often the side product of pulpwood harvests.
	Pulp mills are significant bioenergy producers (e.g. energy for paper mills and district heating). Harvesting and selling sawlogs generate the single largest source of income for forest owners, and thereby the largest motivation for selling wood to the industries.
Sawnwood and plywood	The volume of sawlog removals determines to a significant extent the mobilisation (supply) of forest biomass; roundwood, forest residues (branches, tops, stumps), and in the end, also industrial residues (bark, chips, sawdust).
Particleboard	Volume of wood-based panel markets (excl. plywood) determines also the availability of sawmilling residues for bioenergy production, because it competes from the same raw material, especially in Central Europe.
Biorefineries related to forest industry	The energy production (like biofuels) of forest industry biorefineries is partly dependent of the synergies with the forest products production. The better the prospects for forest products, the better the prospects for forest industry integrated biorefineries.

The forest products markets long-term outlook studies are rarely published in scientific journals. They tend to be published regularly by private companies and they are expensive (many thousand euros), such as RISI and International Wood Markets Group Inc. Outlook studies. FAO and United Nations Economic Commission for Europe (UNECE) produce forest sector outlook studies, typically every 5 years or so. Some researchers produce occasionally research studies, or commissioned assignment studies, on the forest industry market outlook, typically focusing in one particular product category or regional area.

Here, we consider some critical questions, or important issues that have not received enough attention when considering forest sector outlook studies and their potential implication to bioenergy markets. These questions should be studied more carefully, when considering the long-term development of forest biomass for bioenergy purposes. The views, or critical questions, are based mainly on reviewing and synthesising of the studies shown as references (see the reference list).

From reviewing the literature, and taking into account more recent information about the market developments, and the data that was not yet available for many of the studies reviewed, the critical questions shown below are raised. Note that there are number of other issues as well, but these are considered to be the three most important questions:

1. Updated analysis of the impact of European wood products industry's impacts to forest biomass supply for bioenergy purposes. For example, the volume of sawnwood production is critical factor determining the mobilisation of forest biomass, both in terms of the level of harvests, and the supply of residues (chips, pellets) for bioenergy purposes. The financial crises and has potential impacts also for the structure of wood products industry (not only short term business-cycle impacts) in many countries. These, in turn, may have important implications to forest biomass supply, and they have not yet been analysed in detail. For example, the extensively cited EUwood study (Mantau et al. 2010) do not consider these.

2. The structural changes in global pulp and paper markets, such as the declining communication paper consumption in many OECD-countries, and the resulting impacts to paper and pulp production. This, in turn, has important implications to bioenergy production, as well as pulpwood consumption. These have not been analysed in detail. For example, the EUwood study (Mantau et al. 2010) is likely to overestimate significantly the EU pulpwood demand up to 2030, and also the bioenergy production in pulp mills. New updated and more realistic analyses are needed. This will have also significant impact on the forest bioenergy markets. (Note that the EUwood study neither analysed the impact of international trade in biomass, or the impact of market (price) adjustment for the demand and supply of biomass).

3. Many economic studies indicate that *services are an important megatrend in the 21st Century*, and they are changing the competitive advantages of OECD countries. To simplify, if in the 20th Century many of the OECD countries still had strong industrial sectors, with large volumes of manufacturing production located in the countries, the situation is different in this Century in many ways. The emerging economies, like the BRIC countries, are the manufacturing powerhouses of 21st Century, and a significant degree of assembly and actual industrial production has moved from OECD countries to these countries. At the same time, *the OECD economies have become more focused on the services related to manufacturing*. In practice, this means head quarter functions, such as, management, immaterial rights (patents, licensing), engineering and software development, monitoring, planning and servicing, marketing, etc.

4. One critical question that the above development poses to forest biomass based bioenergy production is: To what extent the OECD countries have competitive advantages in the actual manufacturing (production) of bioenergy, and to what extent they will instead be the service providers for this production? For example, to what extent the large scale manufacturing of biofuels is going to take place e.g., in BRIC countries, and to what extent Western Europe will be more focused in managing and servicing this production (through global companies)? This question has not really been studied so far, but it will have significant implications to bioenergy outlook assessments.

3.2 Pulp and Paper Markets

3.2.1 Introduction

The global and the European Union pulp and paper markets are undergoing more significant structural changes than for decades. First, for the last 7 years, in many OECD countries the paper and paperboard production and consumption has been either stagnating or declining. This is longer than any time during the last half a century. The reasons behind the regressive development are both cyclical ones related to economic downturn, and structural ones related to digital media replacing the need for communication or graphics papers.[6] In addition, there has been major movement of

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[6] Paper grades used for communication purposes are called *communication papers* or *graphics papers*. They consist of two main paper grade types, *printing and writing papers* and *newsprint*. Printing and writing papers is often disaggregated into four major grades: coated woodfree (freesheet), uncoated woodfree (freesheet), coated mechanical and uncoated mechanical papers. In terms of world consumption of graphics papers, the most significant grade is the uncoated woodfree, accounting for over 37 percent of the total graphics paper consumption, followed by newsprint (23 percent).

production capacity from West (mainly OECD-countries) to East (Non-OECD countries). This change is illustrated in the Figure 3.1.

% of world production
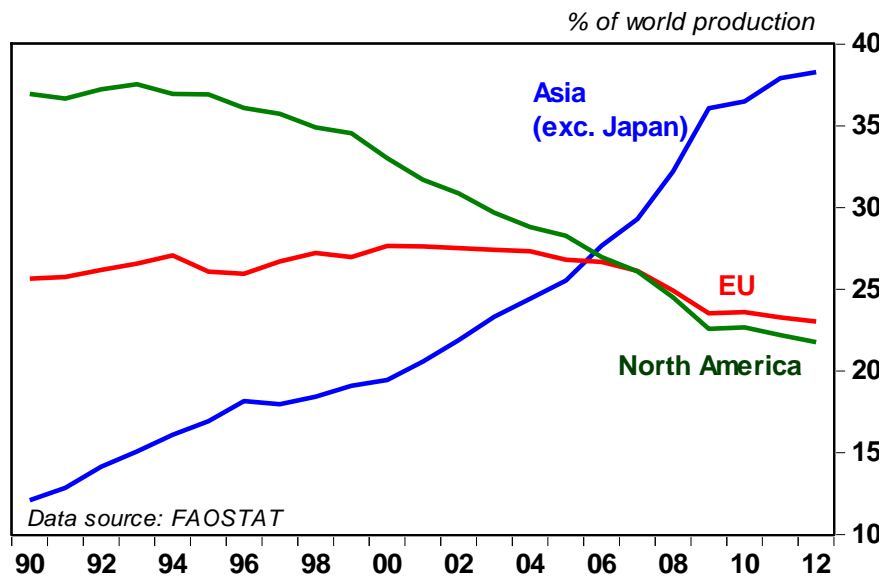
Figure 3.1 Market Shares of World Total Paper and Paperboard Production in 1990–2012.

European Union graphics paper consumption and production has been declining from the maximum levels in 2006–2007 by 25 to 27 percent in 2013, respectively. The total paper and paperboard production and consumption decline from 2007 to 2012 has been 10 to 13 percent, respectively. The pulp production has declined by 11 percent in the same period. In line with the stagnating or declining consumption and production levels, the real prices of paper products have continued to decline. The structural changes are enhancing this trend (Hetemäki et al. 2013). However, the significant exception from this in the 21st Century been the increasing pulp prices. The pulp price trend reflects particularly the increasing demand for wood fibre in emerging economies, which has also impacted the world prices.

EU Grpahics Papers 1990-2013

million tons

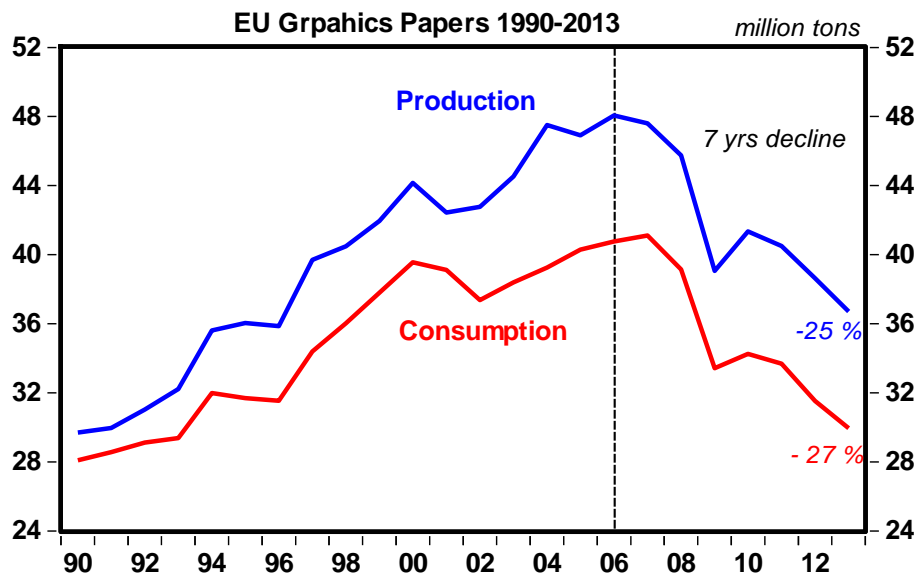**Figure 3.2** EU Graphics Paper Consumption and Production in 1990–2013.

For many experts, these changes in the global and EU pulp and paper markets have become as a surprise. For example, the extensively cited recent projections by e.g. UNECE-FAO (2011) European forest sector outlook study (EFSOS II), the Mantau et al. (2010) EUwood study, and Buongiorno et al. (2012) global and North American outlook studies project increasing consumption and production of paper products to 2030 or even 2060. In essence, the past trends are more or less projected to continue, and no structural changes are expected (Hetemäki et al. 2013, Hurmekoski and Hetemäki 2013).

On the other hand, some experts and studies have been projecting structural changes and stagnating or declining graphics paper markets already for some time, such as Boston Consulting Company (1999, 2007), Hetemäki (1999, 2005), Hetemäki et al. 2013 and RISI projections in the past 6 years or so. The development is not only impacting the graphics paper sector, which has experienced the most significant changes amongst the different paper grades. Also, the packaging and paperboard market growth has been stagnating in USA and Western Europe in 21st Century, both due to the economic downturn and structural factors. The latter relate to the development of consumer and industrial goods manufacturing increasingly moving to emerging economies, such as China. As the production has moved there, so has the packaging of the goods.

Whether we assume the OECD countries pulp and paper markets follow the trends from the 20th Century also in the future, or instead project the future development to reflect the patterns from the last 10 years or so, make a significant difference for many forest sector related factors. They do not only have impacts to income, employment, and industrial roundwood consumption, but also to bioenergy markets. The latter relate e.g. to changes in roundwood and sawnwood chips demand and supply, pulp mill energy generation, and possibilities to integrate new biorefineries to pulp and paper mills.

In this chapter, we will review and analyse in more detail the recent outlook studies for global and European pulp and paper markets, the impact of different scenarios, and raise the questions needing further analysis.

3.2.2 The Outlook of the Global Paper and Paperboard Sector

The pulp and paper industry is highly diversified in terms of products, raw materials, product qualities, distribution channels, and end-uses. For instance, tissue, cartonboard and newsprint have very little in common, apart from their basic production processes and being capital intensive. Pulp, paper and packaging boards are typically intermediate products, used as inputs in the production of other value-added products while some products, such as tissue and office papers, are generally distributed to consumers without further conversion.

In 2010, the world total quantity of paper and paperboard products produced was 400 Mt, with an estimated value of U.S. $ 360 billion (using the 2010 average export unit value as a basis of valuation).[7] In terms of the quantity produced or consumed, packaging and board products are the largest paper product sector. They accounted for 52 percent of the total paper and paperboard production in 2010; whereas the share of printing and writing paper and newsprint together was 45 percent (Figure 3.3). However, the pattern of export value of these products is reversed; communication papers accounted for 53 percent, while packaging and board just under 40 percent in 2010.

At the global level, aggregate paper and paperboard production has continued to grow an average of approximately 2 percent per annum during this Century. If this trend continues in the current decade, global production will increase by 83 Mt from 2010 to 2020, i.e. about the same amount as North American consumption was in 2010 (81.5 Mt). However, this growth pace is unlikely to continue in the future. As indicated by the 5-year moving average annual per cent change of the paper production growth rate, the trend has been declining since the end of 1980s (Figure 3.4). In the 1980s, the average growth rate of world paper and paperboard consumption was 4.4 percent in 1990, but it has slowed to 0.4 percent in 2012. Clearly, this is a significant change in the growth rate, with many implications.

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[7] According to FAO, the average world export value of paper and paperboard in 2010 was US$ 902 per t (FAOSTAT). The world production of paper and paperboard in 2010 was 400 Mt. If we value this production by the export value, the total world paper and paperboard value was 902 x 400 = 360 800 million US dollars or 360.8 billion. All the data related to forest industry given in this chapter is either from FAOSTAT or RISI.
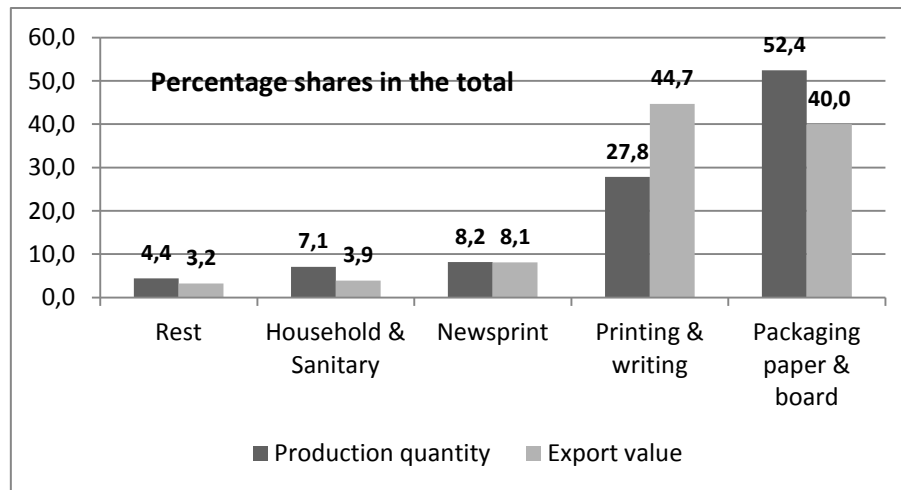
Figure 3.3 The Production Quantity and Export Value Shares (%) of Paper Product Groups in 2010 (computed as percentage of the total world paper and paperboard production and export value in 2010. Data: FAOSTAT).
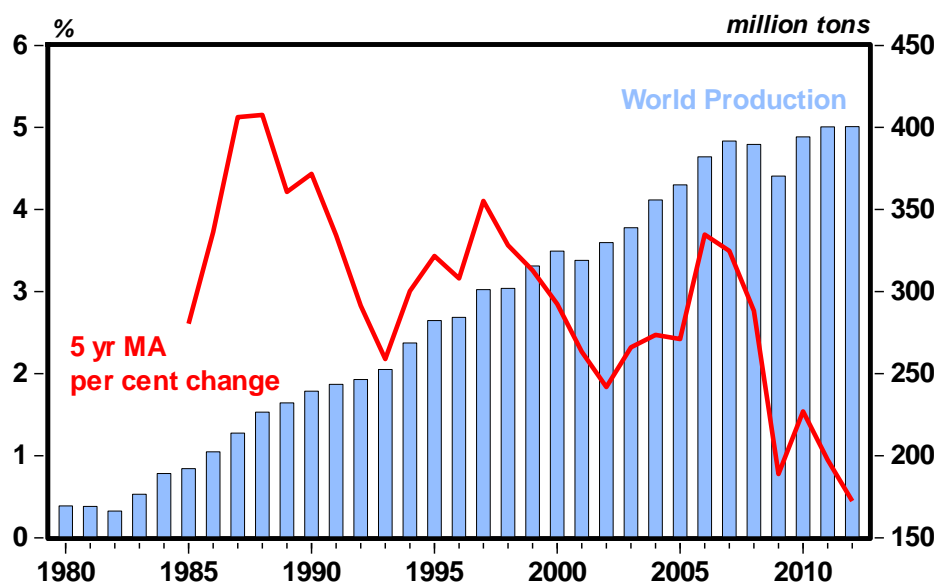
Figure 3.4 World Paper and Paperboard Production and 5-year Moving Average (MA) (percent change) in 1980–2012 *(Data: FAO).*

The major reason behind declining overall global growth appears to be driven by saturated or declining consumption of some major paper products in high-income OECD[8] countries. If global paper and paperboard markets were divided into two regions, *industrialised high-*

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[8] The mission of the OECD is to promote policies that will improve the economic and social well-being of people around the world." (www.oecd.org). It has 34 member countries in North and South America, Europe, and the Asia-Pacific region.

income regions/countries, and *primarily lower-income countries*, the differences in consumption patterns become more striking. We define *high-income regions/countries* to be North-America, Western-Europe[9], Japan, Australia and New Zealand, and the *low-income countries* are all others.

An interesting observation is that in 2000 paper and paperboard consumption in the high-income region/countries was twice that of low-income countries; but already in 2010, aggregate consumption was higher in the low-income countries. Thus, within a decade, there has been a striking change in these markets. A second observation is that, at the turn of this century, consumption has become saturated and even declined in high-income countries. If consumption trends of the last decade were to continue in the coming decade, consumption in the high-income regions/countries would decline by 2020 to the level it was in late 1980s, while in the low-income countries, consumption would be over 50 percent higher than it was in 2010.

One of the major factors influencing growth in low-income countries has been the extraordinary development in China. Between 2000 and 2010, Chinese paper and paperboard consumption grew by 143 percent. However, this was outstripped by a 182 percent increase in Chinese production. This dramatic influence has global implications for the paper and wood fibre markets.

This global paper consumption perspective does not reveal large differences between major regions and various paper grades. What are these differences, and the factors behind the different patterns? Moreover, what is the outlook for the next 10–20 years? These are the questions we next analyse in more detail. Before doing this, a short description of the approach used for the analysis is helpful. The market outlook prospects are described by use of simple trend models which can be viewed as "base scenarios" where markets and market structures are assumed to follow the same patterns for the next 20 years as they have over the 2000–2010 period. The year 2000 was been chosen for the base year for the trend analyses, because for many paper grades and regions data from 20th Century reflect a different structure than what has been experience in the past decade in the global paper markets.

However, the longer to the future we project, the more likely it is that even the most recent trend patterns will neither continue as such. Inevitably, there will be new structural changes emerging that will create dislocations for the trend of the past decade. Still, the trend projection is a helpful baseline against which we can reflect and speculate possible structural changes, and how they would change the projections.

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[9] *Western Europe* is here defined to consist of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

3.2.3 Regional Pulp and Paper Markets and Trade

There are large regional differences in the pulp and paper consumption and production patterns, as seen in Table 3.2. Asia is clearly the largest region in terms of paper consumption and production, about twice as big as the next region, i.e., North America. Perhaps the most striking fact is that Africa's consumption and production are so extremely low compared to other regions. Africa's population (one billion) is roughly equal to that of the total of North America and Europe, but its consumption of paper and paperboard is only about 4 percent of consumption in these continents.

In examining global development of paper markets between 2000 and 2012, the highest consumption growth has been in Asia, both in absolute volumes and in terms of the rate of growth. Latin America and Eastern Europe also show high growth rates, but in absolute volume they are below Western Europe and North America consumption.

Table 3.2 also provides trend projections to 2020 and 2030. The projections show that clearly the most significant paper consumption and production growth would take place in Asia, doubling by 2030 from 2010 levels. Although this is clearly a possibility, as mentioned earlier, this projection has a high level of uncertainty. Paper consumption and production is quite likely to increase in the emerging economies of Asia (but stagnate or decline in Japan) up to around 2015–2020. However, the further the time horizon, the more likely it is that consumption growth will face market saturation and consumption may decline.

The other important message of Table 3.2 is that North American paper consumption and production have declined significantly during the past decade, and logically, the trend projection forecasts this pattern to continue to 2030 barring a shock to the supply/demand system. Similarly, Western European consumption has started to decline during the past decade, but at a slower rate than North America. Although Western European production has increased from 2000 to 2010, one should be cautious to expect this trend to continue. This is because there have been significant fluctuations (ups and downs) in the production during this period, and also recent data (since 2007) indicates that production has been declining. Many Western European companies have been reducing capacity, which appears to be continuing in near term.

The share of international trade in paper and paperboard markets relative to global production has increased slightly in the last decade. Globally, the share of exports to production was on average 27 percent in the 1990s, and increased to 30 percent on average in the 2000s. Regionally, there are significant differences in trade, as seen by the regional net import figures in Table 3.2. North America and Western Europe are the only regions that have been, and are projected to be, net exporters of paper products.

Table 3.2 Paper and Paperboard Consumption, Production and Net Imports in 2000 and 2012, and Projections to 2020 and 2030. *(Data: RISI. M t).*

		2000	**2012**	**2020**	**2030**	**2030 vs. 2012**
Asia	Consumption	109.4	177.2	234.2	303.1	125.9
	Production	96.0	175.2	236.4	309.3	134.1
	Net Imports	13.4	2.0	-2.2	-6.2	-8.2
North America	Consumption	100.7	77.8	62.7	42.5	-35.3
	Production	106.8	85.1	72.7	55.3	-29.8
	Net Imports	-6.1	-7.3	-10.0	-12.8	-5.5
Western Europe	Consumption	81.4	72.8	70.9	65.4	-7.4
	Production	88.6	86.9	90.2	89.6	2.7
	Net Imports	-7.2	-14.1	-19.3	-24.2	-10.1
Eastern Europe	Consumption	13.1	25.0	34.8	45.3	20.3
	Production	12.8	19.9	24.9	30.6	10.7
	Net Imports	0.3	5.1	9.9	14.7	9.6
Latin America	Consumption	19.4	28.3	35.1	43.4	15.1
	Production	14.9	21.0	25.7	31.1	10.1
	Net Imports	4.5	7.3	9.4	12.3	5.0
Africa	Consumption	4.8	8.8	11.3	14.6	5.8
	Production	3.3	4.2	5.3	6.2	2.0
	Net Imports	1.6	4.6	6.0	8.4	3.8
World	Consumption & Production	328.7	401.5	464.7	533.4	131.9

Projections based on trend from 2000-2012.

Historically, Asia has been the biggest global importer of paper, and this trend is likely to continue in the coming decade. However, in China, paper production has expanded in recent years more rapidly than consumption. As a result, Chinese exports of paper and paperboard almost tripled from 2005 to 2010 as exports increased by nearly 2 Mt. According to China's 12th Five-Year Plan for the pulp and paper industry, the country targets total paper and board consumption and production to grow at an annual rate of 4.6 percent to 2015 (Yao 2012).   As there are significant already ongoing projects or investment plans for paper and paperboard capacity increases in China, the balanced growth of production and consumption may require closure of outdated production facilities (Ou 2011, Yao 2012).

Assuming that the trend of the recent decade continues, Africa, Eastern Europe and South America will continue to increase their imports of paper and paperboard. The most significant importer in 2030 is projected to be Eastern Europe. North America and Western Europe will most likely remain the main global exporter of paper and paperboard. However, these trends may be altered by a continuing global economic slowdown, which has significantly reduced paper consumption and production both in North America and Western Europe. In addition, large global paper companies are redirecting investment to emerging Asian and South American regions.

3.2.4 The Impact of Digital Media in the Graphics Paper Sector Background

Paper grades used for communication purposes are called *communication papers* or *graphics papers*. They consist of two main paper grade types, *printing and writing papers* and *newsprint*. Printing and writing papers is often disaggregated into four major grades: coated woodfree (freesheet), uncoated woodfree (freesheet), coated mechanical and uncoated mechanical papers. [10] In terms of world consumption of graphics papers, the most significant grade is the uncoated woodfree, accounting for over 37 percent of the total graphics paper consumption, followed by newsprint (23 percent).[11]

One of the most significant features of global graphics paper markets during the past decade have been the significant rise of low-income emerging economies as consumers and producers of paper products, and the simultaneous decline of many of the high-income OECD countries. As a result, a shift from West to the East has taken place in the global forest products markets. For example, in 2000, the consumption of graphics papers was 2.5 times as high in high-income countries compared to the low-income countries, while levels are almost equal now, and in 2014 the latter countries are projected to have a higher consumption level (Figure 3.3).

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[10] Uncoated free-sheet papers are used e.g. for office and business printing (copiers, computer printers, facsimiles), business forms and envelopes, and commercial printing and writing (stationery). Coated woodfree and coated mechanical papers are used e.g. for magazines and catalogues. The uncoated mechanical papers are used e.g. for inserts, flyers, directories, and books.
[11] Coated woodfree papers accounted for 19.1, coated mechanical for 11.5, and uncoated mechanical for 9.2 percent from the total world graphics paper consumption in 2010.
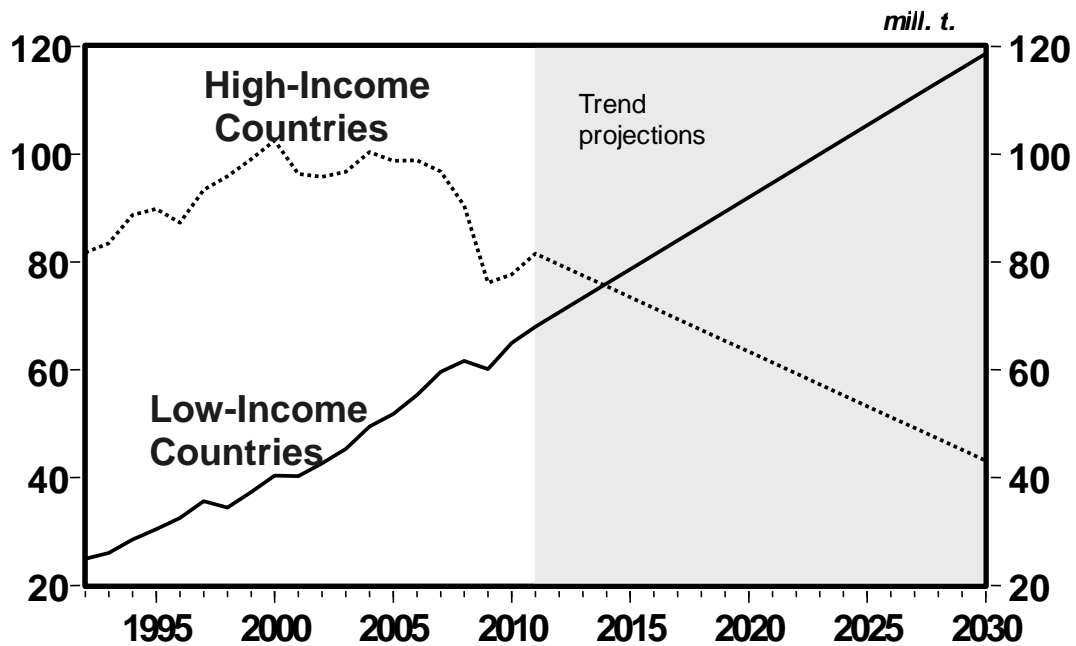
Figure 3.5 World Graphics Paper Consumption in High-Income and Low-Income Countries 1992–2010, and Trend (2000–2010) Projections to 2030 *(Data: RISI).*

Although the Figure 3.5 provides projection up to 2030, it is unlikely that the trends would continue without any changes for the next 20 years or so. For example, it could very well be possible that, say after 10 years, emerging paper consuming economies, such as India, China, Brazil, and Russia, could hit the saturation point in communication paper consumption (e.g. due to consumers adopting increasingly digital media), and consumption would start to stagnate, and even decline. Thus, the trend projection has a high degree of uncertainty, but is still useful as a baseline.

3.2.4.1 Drivers of Market Changes

The basic structure of the models used to project forest products demand has not changed significantly over time (see e.g., McKillop 1983; Uutela 1987; FAO 1999, Zhang and Buongiorno 1997, Buongiorno et al. 2003, Hetemäki 2005). Typically, these are empirical models, such as the Global Forest Products Model (Buongiorno et al. 2003), in which paper consumption is a function of economic activity (usually GDP or GDP per capita), paper demand in the previous year, and the price of the paper commodity. One of the central assumptions behind these models and projections is that per capita consumption of paper products is directly and positively related to per capita income (GDP), and negatively related to the price of the paper product. These assumptions are assumed to be valid across countries and over time. Researchers, industry firms, analysts, government agencies, etc. typically use these drivers when considering the long-term outlook for

market development (see, e.g., FAO 1999, Zhang and Buongiorno 1997, Buongiorno et al. 2003, Hetemäki 2005, UNECE 2011).

Looking at recent developments in *low-income countries*, these assumptions appear to be valid. In many "emerging" economies, rapid economic growth, along with increasing urbanisation and educational levels, are generating increasing demand also for communication papers. For example, in China, India, Indonesia, Poland, Russia and Turkey, all populous countries, communication paper consumption grew from 60 to 100 percent between 2000 and 2010, depending on the country (FAOSTAT). On basis of long-term economic growth projections (e.g. Consensus Economics 2012), and the population projections by United Nations (*World Population Prospects: The 2010 Revision)*, we would expect this trend to continue, at least in the coming decade (Figure 3.5).

However, in case of the *high-income countries*, it is much more difficult to use economic growth as a primary driver for communication paper consumption (UNECE 2011). For example, for North America and Western Europe, it would be problematic to project communication paper consumption to grow as GDP grows, except during the short-run business cycles (Hetemäki and Obersteiner 2001; Hetemäki 2005, 2008; Gordon et al. 2007, Soirinsuo 2010, Hujala 2012).

Figure 3.6 is illustrative of this situation. It shows U.S. newsprint consumption, real GDP, and population data from 1939 to 2010. All these variables were increasing until 1987, after which newsprint consumption started first to stagnate, and later, to decline rapidly. The market behaved before 1987 very much in a way that forest economists and industry analysts expected (McKillop 1983, Uutela 1987, FAO 1999, Zhang and Buongiorno 1997, Buongiorno et al. 2003). Using this type of "classical" model, in 1999, the FAO (1999) projected that the U.S. newsprint consumption would continuously increase up to 2010, when it would have been 16.4 million tons. However, as Figure 3.6 shows, there has been a drastic drop in consumption, and, according to FAO statistics, it had dropped to 4.6 million tons in 2010. That is, almost 12 million tons less than projected by FAO (1999). Viewing this "projection error" from the industry perspective, it equals the annual production of approximately 79 newsprint machines in North America (average size of a newsprint machine being 150,000 tons). Also, the "official" U.S. RPA projection in 2002 forecasted that the consumption in 2010 would be over 11 million tons, about 2.5-times higher than the actual figure (see, Haynes 2002).

The drastic structural change is also reflected in the correlation coefficient between newsprint consumption and GDP: the correlation for period 1939–1987 was +0.97, but for period 1988–2010 it was -0.73. The positive relationship between economic growth and newsprint consumption has ended, and turned to a negative one.
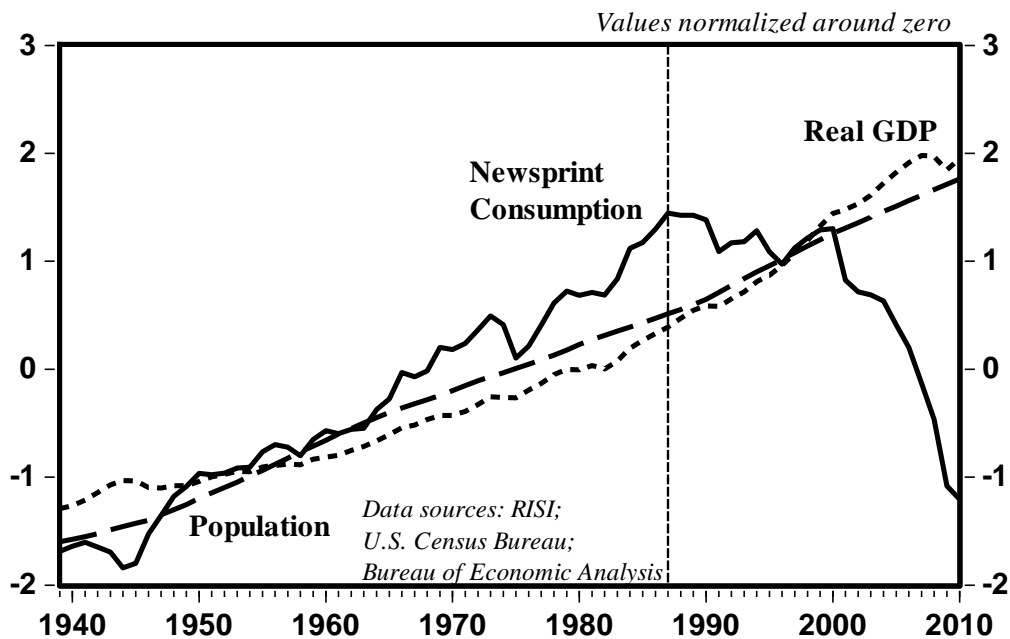
26

Figure 3.6 U.S. Newsprint consumption, population, and real GDP in 1939-2010 (values are scaled by normalising the data series around zero).

Clearly, there are many reasons behind the structural change that resulted in widely different projections relative to actual consumption figures. For example, many commercial printers have switched from newsprint to other paper grades (SC paper); the weight of newsprint has declined from 60 mg to 48 mg; and there have been changes from broadsheet to tabloid newspaper formats (Hetemäki 2005). Yet, the most important factor has been the fact that fewer people are reading newspapers, and newspaper circulation has thus started to declined markedly, as the Newspaper Association of America (NAA) statistics have shown. But, in addition, due to the declining circulation, both business and classified advertisements began to abandon newspapers for digital venues. Thus, fewer pages were needed, and therefore, also less newsprint.

The major reasons for declining circulation and newspaper readership appear to be twofold: first, people increasingly are reading the news on the Internet; and secondly, an increasing number of people do not read newspapers at all. The latter may be a result of many things, but one important factor, as household media surveys point out, is that they spend more time on electronic media (Internet, TV, videogames, mobile phones, tablets, etc.), and have less time and interest for reading newspapers.

It appears, that the U.S. newsprint market development is an anticipatory example what is expected to happen to other communication paper grades, and in other regions. For example, according to RISI (2012) projections for U.S. paper consumption up to 2027, the consumption of magazine paper is projected to decline on average 4.6 percent per year. This is combined with a 2 percent per year loss in magazine circulation and a 3 percent

per year loss in ad pages. At this rate, paper usage will be cut in half from 3.0 million tons in 2011 to 1.4 million tons by 2027, a net loss of 1.6 million tons of demand.

Moreover, the impacts of digital media on print media and the paper industry are universal. Electronic communication supersedes print media in New York, Moscow, Peking, or Nairobi in exactly the same way (Hetemäki 2010, PricewaterCoopers 2011, Hujala 2012). However, in emerging economies, due to rapid economic growth and urbanisation, there is still a clear *net increase* in communication paper consumption. In addition, digital media impacts all printed communication forms, such as magazines and companies' annual reports (mainly coated mechanical and woodfree papers), business and office forms (uncoated woodfree paper), and home delivered advertisements (mainly uncoated mechanical paper).

However, there are large differences in the timing and magnitude of the impacts between countries and paper grades, as shown in the differences in the two biggest Western Europe communication paper markets, Germany and the United Kingdom. According to RISI data, newsprint consumption in Germany has declined only slightly from 2000, and printing and writing paper consumption is practically equal (although clearly lower than at the height of 2007). In contrast, in the United Kingdom, newsprint consumption and printing and writing paper consumption have declined 24 and 22 percent from 2000 to 2010, respectively.

If high-income countries consumption follows the trend of 2000–2010 into the next decade, consumption would *decline* by 38 percent in 2020 from its maximum level in 2000. In contrast, in the same period, in low-income countries, it would *increase* by 128 percent. The *world net increase* would therefore be 9 percent from 2000.

One significant unknown is when and to what extent electronic media will start to replace print media in the low-income region? In 2010, the low-income region population weighted average Internet penetration rate was still only 17 percent, which is what it was in U.S. in 1997. But in some major low-income countries change is taking place rapidly, as in China. According to *Internet World Stats,* in China there were 538 million Internet users in June 2012, which is the largest number for any country. However, the Internet penetration rate is still only about 40 percent, whereas in U.S. it is estimated to be 78 percent. But the Internet penetration in China grows very rapidly – if the trend of last five years continue, China's penetration rate will reach in 2018 the same level U.S. has currently.

In summary, given the rapid spread of Internet and electronic media also in the low-income countries, it may be that the current rapid consumption growth may weaken already in the coming decade. Indeed, there are already indications of this happening. For example, the Chinese newsprint consumption growth rate has already started to decline: in 1995–2004, the consumption grew on average by 15.9 percent per annum, whereas in 2005 to 2011 this figure was only 3.6 percent (RISI data).

3.2.4.2 Declining Price Trend

The discussion of the impacts of digital media on the graphics paper sector is very much focused on what happens to paper consumption. However, from the perspective of paper industry company profitability, it is important to draw attention to the potential *price impacts* that arise from changes in the marketplace. The increasing competition between print and digital media has led to a reduction in pricing power for the paper sector. Companies in the paper industry are not simply competing against other paper companies, but increasingly they are also competing against digital media companies, who provide alternative platforms for information dissemination and publishing (Hetemäki 2008, Green 2012). In the face of this increasing competition between print and electronic media, publishers of print products seek to cut operating, materials, and other costs, which is intended to lead to lower, more competitive prices of their paper products. In short, *communication paper prices* are also increasingly determined by digital media development. Indeed, the real price of communication papers has been declining in the past decade. In recent years, the average real price has been around 30 percent lower than in the beginning of the century.[12]

As a result of the competition from digital media, the pulp and paper industry needs to implement strategies to adjust to structural changes in communication paper markets. First, the industry can continue cutting production costs and increase productivity through investment in modernisation. Another pathway to competitiveness is the application of information technology for intra-company business processes and inter-company connectivity with exchange partners. Third, companies can reduce capacity (close mills and paper machines) in order to maintain the supply-demand balance, and maintain/gain pricing power within the markets they serve. This is what companies have been doing in recent years in North America and Western Europe and has been an essential tactic to keep their current businesses profitable. Of course, for some companies the capacity closures may not be a result of well-planned strategic decision making, but simply a *force majeure*, in that they have no other possibility. Also, companies merge to increase market share and gain market and pricing power. Finally, the paper industry can innovate new products for which there will also be growing markets in the high-income industrialised countries (see section 5.5).

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[12] Based on FAOSTAT data, and computing the world price as an average of the export and import unit prices, and deflating it with world commodity input price index from IMF.

3.2.5 Packaging Sector Increases Paperboard Consumption

3.2.5.1 Overview of Packaging and Paperboard Products

In the previous section it was shown how the development of information technology and digital media is resulting in substitution impacts and declining consumption and price trends for graphics paper products. In contrast, information technology is not expected to have such a negative effect on paperboard consumption. For example, a rapidly growing consumer Internet trade increases the need for packaging, which translates to growth in paper products used for packaging. In this section, we focus on the current state and outlook of the global paperboard and packaging markets.

One of the most important driving forces in determining the success of paperboard is how well it can compete against other packaging materials. Currently packaging paper and paperboard are the most important packaging materials in terms of market share. Their value share of the total global packaging products is 38 percent, while the second largest is plastics with a 34 percent share (WPO 2008). As these two product groups dominate global packaging, their relative competitiveness determines how the paperboard sector will develop in the future.

Global consumption growth of packaging paper and paperboard has been stable during the last two decades with an average annual growth rate of 3.4 percent (based on the RISI data). Although packaging markets are affected by global economic changes, economic recessions have generally had smaller negative impacts on paperboard markets than on graphics papers markets (Finnish Forest Sector Economic Outlook 2011). Global growth of paperboard production is mainly correlated to the rapid consumption growth of containerboard that is used for bulk packaging of industrial commodities. According to the RISI data, cartonboard consumption has been growing slower, but the growth rate has increased during the end of the 2000s. The cartonboard product group includes folding boxboard, liquid packaging board, solid bleached sulphate board and white lined chipboard. These grades are used for many kinds of consumer packaging such as food, liquor, light industrial products, medicine, health care products, cosmetics, and electronics. The World Packaging Organization (WPO 2008) expects, that growth opportunities exist for packaging in such areas as fresh food and ready-to-eat meals especially in emerging markets in developing countries. Additional opportunities exist for suppliers in beer and mineral water consumption especially in Eastern Europe, the Middle East and Asia. Healthcare and cosmetics are also fast growing end-use areas for cartonboard. Despite the significant growth possibilities for cartonboard, plastic packaging is a challenging competitor. For example, according to WPO (2008) rigid plastics have been, and will be in the future, the fastest growing packaging material.

3.2.5.2 Regional Developments in Paperboard Markets

The largest consumer and producer countries of paperboard are the U.S., China and Japan. With declining production, Japan has become more dependent on paperboard imports during the last decade. An important structural change that has affected the global paperboard markets is the remarkable consumption and production growth in Asia resulting from the rapid economic development of China (Table 3.3). In contrast, consumption has declined in the U.S. and in Western Europe. An important reason for this was that production of consumer and industrial goods have increasingly been transferred from OECD-countries to emerging economies, such as China. As a result, packaging also has migrated to these regions. However, a significant portion of packaging board produced and "consumed" in China actually ends up in the U.S. and Western Europe through Chinese exporters (Hetemäki & Hänninen 2009). North America and Western Europe clearly produce more paperboard than they consume, and have been important exporters (Table 3.3). The production growth in China and overall decline in demand during the recession of 2008-2010 has led to capacity cuts in the paperboard industry in North America and Western Europe. Africa, Eastern Europe and Latin America are net importers of paperboard. In particular, Africa's consumption and production volumes are very low compared to the other regions.

Table 3.3 Paperboard Consumption and Production by Regions (in million metric tons).

Region	Consumption			Production		
	1992	2000	2012	1992	2000	2012
Africa	2	2	4	1	2	2
Asia	26	41	84	24	39	82
North America	37	44	40	41	48	46
Latin America	5	9	14	5	7	10
Eastern Europe	4	6	12	5	6	10
Western Europe	23	30	30	24	31	34

Source: RISI, includes containerboard and carton board

International trade of paperboard in terms of export and import volumes doubled between 1992 and 2010. However, the volume of trade relative to production has been rather stable: the share of exports to production has been around 20 percent on average during

this period. A number of important changes have occurred in the regional net trade (exports–imports), of which the most important is the volume growth of West European net exports between 1992 and 2010. In 2010, Western European exports were 4.6 million tons larger than imports. North America is the other region where exports have increased in relation to imports. Western Europe and North America will continue to be important exporters of paperboard in future, due to the stagnating consumption in these regions.

Eastern Europe, Latin America and Africa have become more dependent on imports. In Eastern Europe, the development of the Russian market is important, as it covers about one-third of Eastern European production and consumption. Russia's paperboard imports have risen quickly boosted by domestic consumption. Import growth will continue in Eastern Europe (particularly Russia), Latin America and Africa. Asia will continue investing in new capacity in order to meet rapidly growing demand in the region.

3.2.5.3 Changes in Paperboard Prices

The rapid increase in the production of paperboard in the low-cost emerging countries (e.g. China) in the past decade seems to have changed the paperboard world price pattern (Figure 3.7).[13] In the 1990s, there was significant cyclical variation in paperboard prices, but no clear declining trend. However, during the last decade, when rapid production enlargements started in new Asian low-cost countries, a clear declining price trend is evident. This changing world price pattern has been a particular challenge for the profitability of the North American and Western European producers.

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[13] The price development of paperboard is described by the average of world import and export unit values in US dollars (Faostat). Prices were transformed to real prices by deflating nominal prices by world commodity industrial inputs price index (IMF). Prices are for wrapping and packaging paper and paperboard (Faostat code 1681).
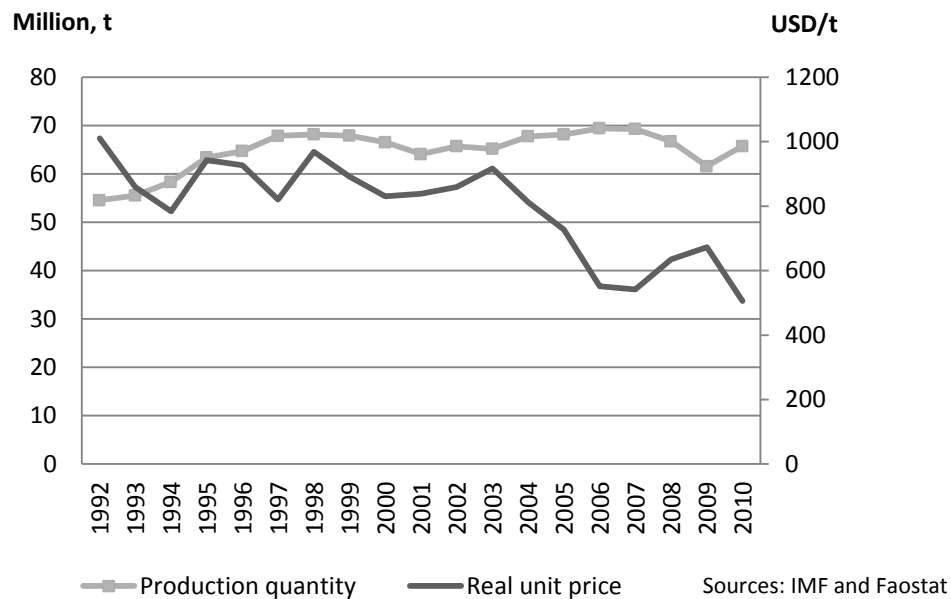
Figure 3.7 Production of Wrapping and Packaging Paper and Board in High-Income Countries and World Real Price, 1992–2010 (Sources: IMF and Faostat).

3.5.2.4 Drivers of Paperboard and Packaging Markets

What are the main drivers that help to explain past developments and anticipate the future of the paperboard and packaging sector? These are questions that have not been thoroughly addressed by academic researchers. Previous studies on the paper industry have focused mainly on graphics papers (e.g. Zhang and Buongiorno 1997, Laaksonen 1998, Hänninen and Toppinen 1999, Hetemäki 1999 and 2008, Hetemäki and Obersteiner 2001, Bolkesjö et al. 2003). On the other hand, academic research on paperboard markets has been relatively scarce.

The studies that do exist have focused on different aspects of the paperboard sector. For example, Li and Luo (2008) examined consolidation of the paperboard industry. Their results for the U.S. linerboard industry suggested that consolidation has not necessarily resulted in higher market prices. One reason for this was suggested to be a low concentration ratio. In another study, Löfgren and Witell (2005), suggest that quality attributes of packaging, such as recyclability, influence the decisions to buy and use packaging products. Also, the findings of Rokka and Uusitalo (2008) emphasise the increasing importance of environmental dimensions of packaging in product choices. In contrast to the scarce academic research on paperboard sector, there are many empirical surveys and reports made in industry organisations and consulting companies working in the packaging sector. According to the World Packaging Organization study (WPO 2008), the most important demand drivers of packaging and packaging materials are economic development, population growth, consumption habits, Internet trade and technological development.

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Table 3.4 Consumption of Paperboard Per Capita and Projections for Population Growth by Regions.

Apparent consumption of paperboard, and population	Asia	Western Europe	Eastern Europe	Latin America	North America
2010: consumption kg/per capita	2.2	7.3	3.5	2.0	11.6
2010:population, millions	4164.3	189.1	294.8	590.1	344.5
Average annual growth rate of population by 5 year periods 2010-2015,%	0.99	0.15	-0.17	1.07	0.86
2015–2020,%	0.85	0.16	-0.21	0.93	0.80
2020–2025,%	0.71	0.12	-0.29	0.80	0.74
2025–2030,%	0.57	0.08	-0.38	0.66	0.67

Sources: Faostat and the United Nation (UN) (2011), population growth, medium-fertility variant 2010–2100.

In the following section, we present two alternative trend projections for paperboard consumption in five regions. Consumption is analysed based on the figures for total consumption volumes as well as for volumes per capita (consumption/inhabitant). According to the United Nations estimates (UN 2011), population growth has been shrinking gradually in all the five regions during the 1990s and the 2000s and anticipated to continue to 2030 (Table 3.4). For Eastern Europe, the UN (2011) estimates indicate negative population growth also in future.

In the first projection, we keep the consumption/per capita at 2010 levels and assume that only population growth (UN 2011) will determine future total paperboard consumption. Figure 3.8 indicates growth rate changes for paperboard consumption in different regions based on this scenario.

For emerging markets, Asia, Eastern Europe and Latin America, the projections probably underestimate future development. In these regions, current consumption of paperboard per capita is clearly lower than in North America or Western Europe (Table 3.4). The increasing trend in industrial investments and production of industrial commodities in emerging countries will probably increase their packaging demand and consumption of containerboard and carton board per capita. WPO (2008) estimates that the emerging

markets are also areas where especially food and fresh products packaging is growing, which are possible new geographical markets for the carton board industry. For North America, the projection shows continued growth in consumption in future, but is premised on sluggish growth observed in the 2000s.
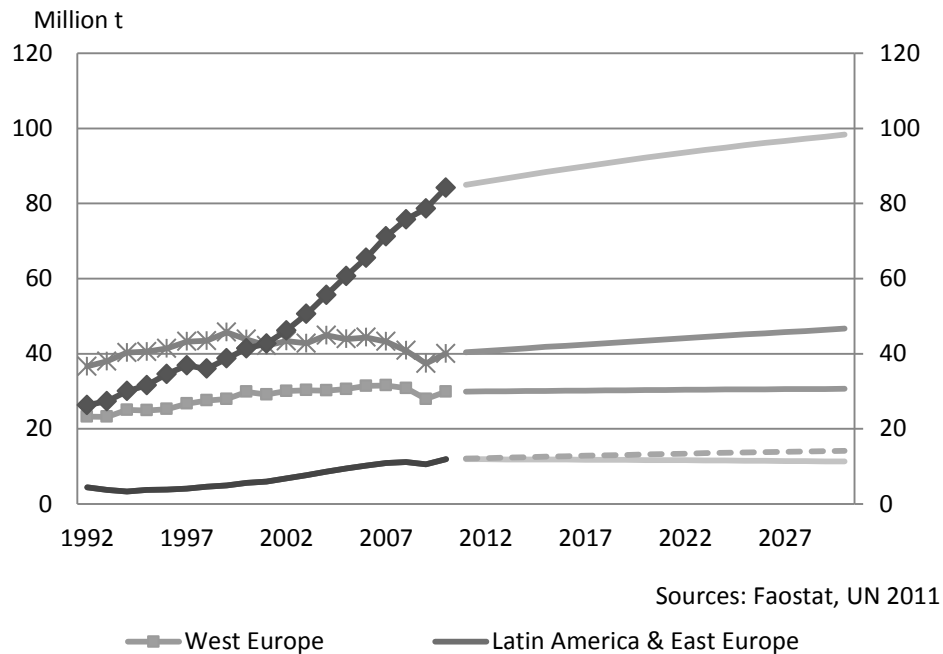
Figure 3.8 Paperboard Consumption by Regions in 1992–2010 and Projections Based on Population Growth for 2011–2030 (dotted trend line is for Latin America).

The second projections are based on linear trends calculated for consumption per capita for the period 2000–2010. As mentioned earlier, globalisation has rapidly changed the structure of the global forest industry and product markets during the 2000s. Paperboard consumption per capita started to decrease in North America, and to stagnate in West Europe. In the other areas, where consumption per capita is clearly lower than in the last mentioned regions, the figures show steady growth: The fastest growing area is Eastern Europe. Even small changes in consumption per capita will have a very large effect on the total absolute volume of consumption. The second projection (Figure 3.9) indicates 77 percent lower paperboard consumption for North America than the first projection in 2030. For Eastern Europe, the second projection indicates consumption levels that are two times larger and for Asia the forecast is three times larger than the first projection.

Figure 3.9 Regional Packaging and Paperboard Consumption and Trend Projections (per capita).

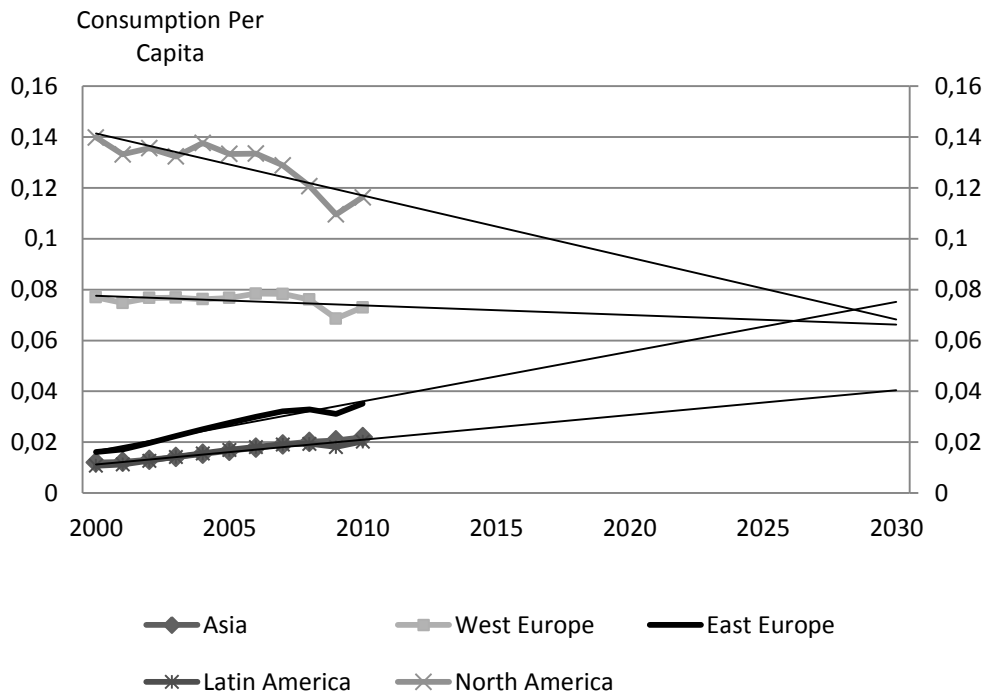In summary, the two projections differ considerably, but they may help in assessing possible future developments in the paperboard sector. Industrial production and export packaging will continue to grow in Asia with a concurrent relatively lower consumption of paperboard for packaging in traditionally large producer regions in North America and Western Europe in the future.

An important source of uncertainty in global paperboard markets is China's rapid economic growth rate and concurrent packaging consumption. This is an issue which is very difficult to project. Another important source of uncertainty and potential opportunity relates to the development of new packaging materials and the ability to innovate new packaging products in reaction to changing needs and habits of consumers. Substitution from alternative materials, particularly plastic, will influence the development of new wood-based packaging materials. An example of an emerging product/market is intelligent packaging which combines wood fibres with modern digital information technology, such as interactive pharmaceutical packages that remind people to take their pills with a programmed frequency. Another example is incorporating new technology in packaging, providing information about food spoilage, which could prevent huge volumes of food waste in the chain of food retailers, wholesalers or consumers.

Although currently of paperboard products are decreasing in West Europe and North America, the growth of food packaging may offset this decline. Larger production volumes will be needed also to satisfy the growing consumption of tissue paper.

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Packaging materials and tissue paper are typically the most profitable to produce near their end use and final customers, because of high unit transportation costs. For example, carton board production for food packaging is typically based on coniferous virgin fibre that is available in the traditional producer countries of North America and Western Europe. On the other hand, tissue products are relatively expensive to transport, and therefore, they tend to be produced near the consuming markets.

Finally, environmental concerns are likely to be an important determinant of packaging sector development in the future. This is positive for the paperboard sector which uses renewable raw materials relative to the main competing fossil -based plastic products.

3.2.6 Implications of Paper Markets on the Wood Fibre Demand

3.2.6.1 Global Development

What would be the implications of trends and outlooks for paper and paperboard consumption and production on the markets and trade flows for wood fibre raw material (wood pulp, recycled paper, and pulpwood)? In order to shed light on this question, we first start by analysing the recovered paper and wood pulp inputs at the global level. Then, we analyse the recycled paper recovery and utilisation trends at the regional level. Finally, we discuss the outlook for pulpwood demand.

Recovered paper (Figure 3.10) has become by far the largest fibre type used in paper making.[14] Its input share in paper making has grown from below 40 percent in the beginning of 1990, to 57 percent in 2010, while wood pulp share has declined from 60 to 43 percent. Amongst the different wood pulp grades, bleached hardwood kraft pulp (BHKP) has increased substantially in absolute volume, and has also gained input share marginally from 14 percent in 1992 to 15 percent in 2010. All other grades of wood pulp show decline in absolute volumes except unbleached kraft pulp, which has been relatively stable during last 20 years.

Western European *paper recovery rate* has recently reached 75 percent of the paper consumed, which is assumed to be close to the practical limit for the region.[15] The recovery rate in Germany was 80 percent in 2010; however, a more conservative assumption was applied for 2010–2030 period for the region as a whole. The North American paper recovery rate is second highest at around 63 percent in 2010. It is projected that North American paper recovery rate will increase following the trend from the past decade until reaching 70 percent soon after 2015, and then remain stable. In

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[14] The statistics used in this section are based on RISI data.
[15] *Paper recovery rate* is the same as paper recycling rate, and it can be defined as the total amount of paper and paperboard recovered (collected) as a percentage of the total amount of paper and paperboard consumed.

Asia, the paper recovery rate has been steadily increasing, and was 53 percent in 2010, the third highest rate after Western Europe and North America. It's assumed that the Asian recovery rate will increase until it reaches 65 percent near 2025.
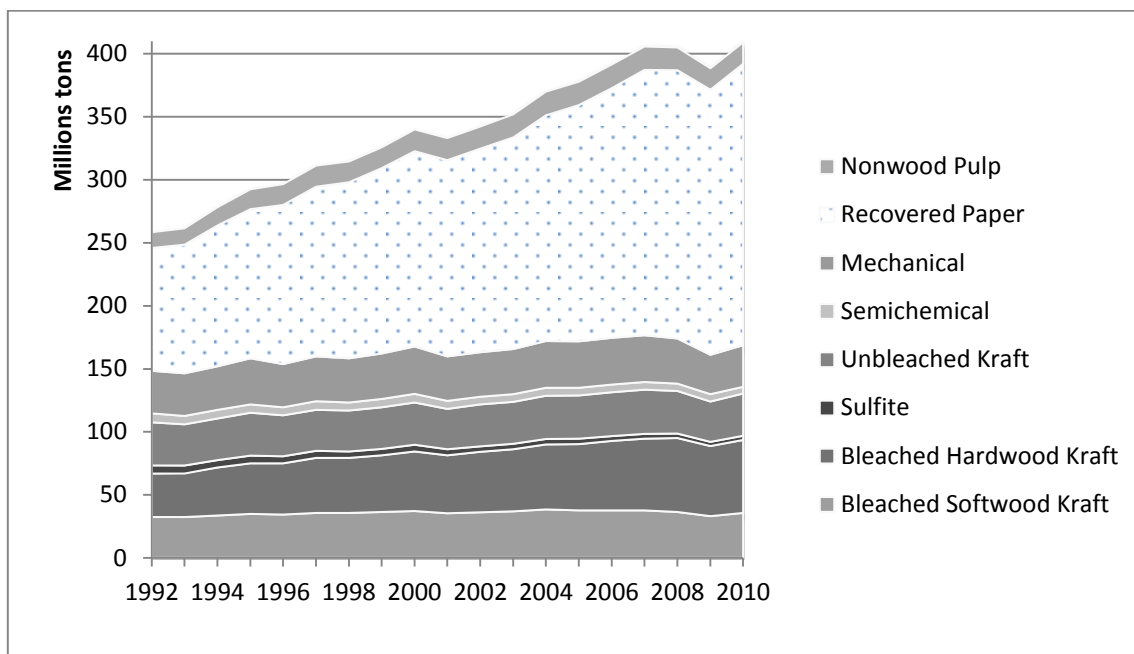
Figure 3.10 Global Paper and Paperboard Fibre Input, 1992–2010 (Data: RISI).

It is also expected that some regional differences in paper recovery rate will remain in the medium term. Eastern European and Latin American recovery rates are assumed to be increasing more gradually, but in line with the last decade's linear trend. African paper recovery rate remains stagnant at around 30 percent.

Recovered paper *utilisation rates* are projected in a similar way – based on the last decade's regional trends.[16] Asia has reached the highest recovered paper utilisation rate of around 69 percent in 2010. That is, out of the total fibre used for paper making, 69 percent was based on recovered paper, and 31 percent on pulp. It is expected that this utilisation rate is close to its upper limit, and it will grow only slightly from this level in the future.

Based on the projected regional recovered paper utilisation rates, and the projected regional paper production volumes, we projected the use of recovered paper in paper making up to 2030 (results not shown here). According to the projections, Asia's use of

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[16] Recovered paper *utilisation rate* can be defined as the share of recovered paper in the total fibre input in paper production.

recycled paper would double from 2010 to 2030. In Western Europe, Eastern Europe, Latin America and Africa recycled paper usage is projected to grow moderately. Only in North America would the recovered paper usage decline in the coming decades. Given these trend projections, in 2030 Asia's share of the global recovered paper use would reach nearly two-thirds.

On the basis of the projected recovered paper utilisation rates, regional paper production volumes, and the projected paper consumption (Table 3.1), regional supplies of recovered paper were estimated. The balance of recovered paper used for paper production and recovered paper supply results in the regional *net trade* of recovered paper (Figure 3.11). Therefore, in contrast to previous projections, the recovered paper net trade projection is not purely a trend projection. Asia has been the largest and the fastest growing importer of recovered paper, but this trend cannot continue much longer, given that Western European and North American exports of recovered paper are not likely to increase in the long-run. The reasons for this are the declining Western European and North American paper consumption and paper recovery rates (they can increase only by a relatively small margin without a resulting very high price level). On the other hand, growing paper consumption and paper recovery rates in Asia will increase the overall supply of Asian recovered paper.
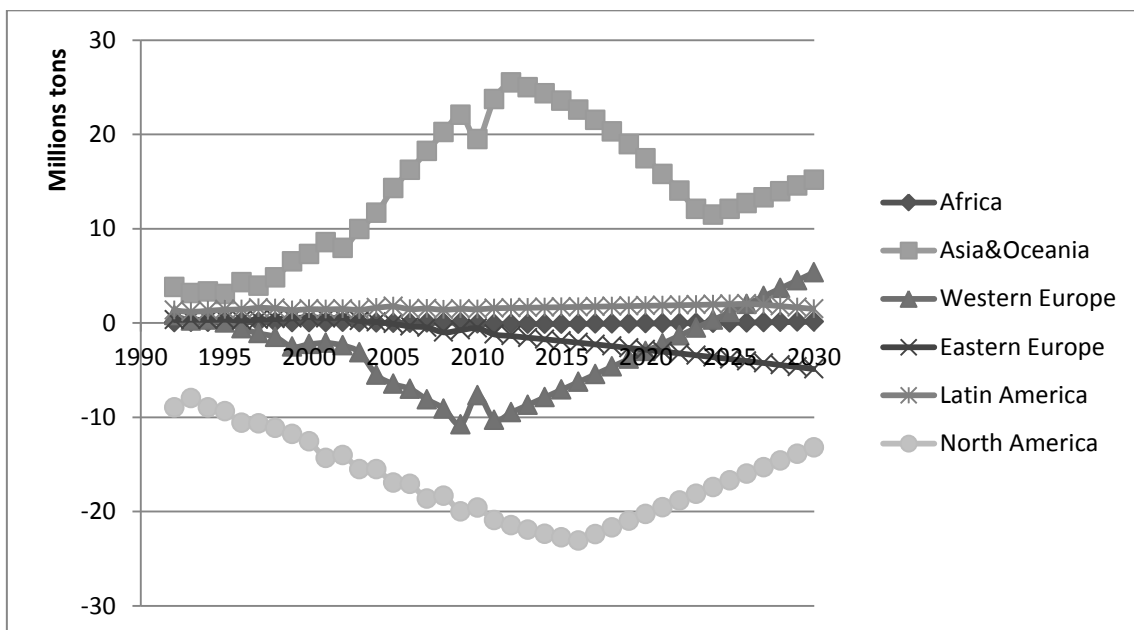

Figure 3.11 Recovered Paper Net Trade in 1992–2010 and Projections to 2030 (Data: RISI).

The wood pulp production trends for the next two decades are linearly projected from the past decade (Table 3.5). Given these projections, Asian and Latin American wood pulp production will exceed North American production, which will decline substantially from its

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current level. In order to supply pulp wood for increasing pulp production in Asia and Latin America, new plantations would need to be established at the same rate as has been observed over the past two decades (FAO, 2006). In addition to the need to maintain the rate of new plantations established, plantation productivity would have to improve in Asia.

One interesting implication from Table 3.5 is that the global demand for pulp wood will grow only marginally due to higher efficiency of using tropical hardwood for pulping compared to using softwood fibre from the Northern Hemisphere. To a large extent, an increase of wood fibre use in Asia and Latin America is offset by a significant reduction in North America due to a decline of wood pulp production. Wood fibre deficits could exist regionally. Should Asia or Latin America fail with plans for expected growth of wood pulp production and increasing wood fibre supply, North America may try to reverse the declining trend for wood pulping.

Table 3.5 Change in Wood Pulp Production and Pulpwood Consumption

	Wood Pulp Production *million t*			Pulpwood Consumption *million m^3*
	2010	2030	Change 2010-2030	Change 2010-2030
Africa	1.8	1.7	-0.1	0
Asia & Oceania	32.1	51.0	19.0	57
Latin America	20.6	45.1	24.6	74
North America	67.8	42.2	-25.5	-115
Western Europe	36.0	34.6	-1.3	-6
Eastern Europe	10.4	12.2	1.8	8
World	168.6	186.9	18.3	17

Table 3.5 shows what the projected changes could imply for regional wood pulp production and pulpwood consumption during 2010–2030.[17] The most important projected changes are significant increases in pulp production in Asia and Latin America, and the decline of pulpwood production in North America by 38 percent from 2010 to 2030. In Western Europe the projection anticipates a slight decline in pulp production in the coming decades. If the projected wood pulp production trends were to realise, Asia would become the largest and fastest growing net importer of wood pulp, and Latin America the largest and fastest growing net exporter of pulp.

These changes in pulpwood production would naturally impact regional pulpwood consumption. Table 3.5 shows that pulpwood consumption would increase from 2010 to 2030 in Latin America and Asia roughly 131 million m^3 accompanied by a decrease in North America and Western Europe of 121 million m^3. However, demand increases in Latin America and Asia would be mostly in hardwood pulpwood, whereas the decline in North America and Western Europe would be mainly softwood pulpwood.

The projections would most likely imply that Asia and Latin America would need to increase their wood pulp production significantly from present levels. This could be achieved by increasing the volume of fast growing plantations, as well as increasing productivity. According to Carle and Holmgren (2008), in their "Higher productivity scenario" (assuming 2 percent annual productivity increase for planted forests), Asia will be able to increase pulpwood supply by 63 million m^3 over 2005–2030 period. This would be sufficient to sustain Asian wood pulp production growth. However, questions remain as to whether newly established plantations and associated productivity increases will be realised to the extent required for the projected levels of growth to take place. On the other hand, if Asia can achieve higher than assumed paper recovery rates, the region can potentially sustain the same level of paper production with lower use of wood pulp. Clearly, if plantation forest productivity growth is not achieved, and the paper recovery rates do not increase, Asia would need to import more pulp wood or wood pulp from other regions.

Another possible option is to attract more investments to the Russian Siberian forest sector. In terms of potential large raw material supply to global pulp and paper industry, there is particular uncertainty with regard to such development in Russia. Russia has the largest coniferous forest resource in the world, but currently the utilisation rate of this resource is low. For example, the a*nnual allowable cut utilisation rate* has typically been under 25 percent (UNECE 2003). There are many obstacles related to the utilisation of this resource, such as poor infrastructure (logistics, forest roads), ambiguous forest ownership legislation and security of wood supplies. However, if the global demand for pulpwood

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[17] It was assumed that to produce one metric ton of wood pulp in Asia, Africa and Latin America, three cubic meters of hardwood pulpwood is required. In North America and Western and Eastern Europe, where pulpwood is largely softwood coniferous requiring higher input, this figure was assumed to be 4.5 cubic meters.

resources increases markedly, the potential pulpwood supply that exists in Russia could start to materialise to a much greater extent than today.

3.2.6.2 EU Pulp and Paper Market Projections

The EUwood study (Mantau et al. 2010) medium scenario projects forest products (or material use) growth of 35 percent from 2010 to 2030, or, an average growth rate of 1.8 percent per annum. That means that the past historical trends are assumed more or less to continue the next two decades. However, given the structural changes in the EU paper and paperboard consumption and production, such a development seems rather unlikely.

Figure 3.12 below shows the EU forest products consumption from 1990 to 2012. The forest products *production* trend (not shown) is about the same as the consumption. The Figure shows that graphics paper consumption started first to stagnate in 2000, and then to decline from 2006 onwards. The other paper and paperboards consumption has a similar pattern, but not as significant drop. Sawnwood consumption growth rate has slowed down after 2000, but started to decline in absolute terms only after 2007, i.e. one year before the economic slump. The important question is to what extent the production pattern changes in the 21st century have been a result of structural factors and of cyclical factors related to the financial crises.

If we compare the pattern of the paper consumption to the GDP pattern in Figure 3.12 we see a clear change from 2000 onwards, indicating that the paper consumption does not anymore grow as clearly along with the GDP. In fact, for graphics paper the relationship has turned negative. This is also indicated by the simple correlation coefficient between GDP and graphics paper consumption, which was +0.96 for the period 1990–1999, and -0.53 for the period 2000–2012. Thus it seems apparent that part of the paper consumption change is due to structural factors (see also Hurmekoski and Hetemäki 2013; Hetemäki et al. 2013). This is indeed a historically significant change, since over 100 years the graphics paper consumption (production) has been increasing in Western Europe, whereas in this century it does not seem to do so anymore.

Let us assume that EU paper and paperboard consumption would develop on average as it has done in the past 10 years (2003–2012 trend). This period consists of six years before the economic slump, and five years after, as the EU GDP bar in the Figure also indicates. The five slump years are of course lower than average growth periods. However, the structural change in the EU paper consumption seems to be accelerating (due to e.g. digital media impacts), and we may expect this impact to increase over time. Thus, maybe on average the 2003–2012 trend in Figure 3.12 is not that bad estimate for future pattern, despite the five slump years. Using this trend in future projections implies that graphics paper consumption would decline from its historical maximum level of 92 Mt in 2007 to 69 Mt in 2030. Thus, it would decline by almost 23 Mt or by 25 percent, instead of increasing by 35 percent as projected by the EUwood study.

A similar trend projection for the EU paper and paperboard *production* would imply that paper production in EU would decline from its historical maximum level of 101 Mt in 2007 to 81 Mt in 2030. Thus, the total paper production would decline by 21 Mt or by 21 percent. In addition to the declining paper consumption, the EU producers are facing increasing competition from the Asian producers (and South American in pulp). This is indicated e.g. by Figure 3.1 which shows the markets shares of paper and paperboard production in Asia (excluding Japan), EU, and North America.

Using the 2003–2012 trend to project EU wood based pulp consumption, and calculating the associated pulpwood consumption required by using a simple multiplier (see the footnote 2 for technical explanation), we get the projections shown in Figure 3.13 According to these results, wood pulp consumption in the EU would decline from 47.5 Mt in 2007 to 30.3 Mt in 2030[18]. Correspondingly (using the multiplier), the demand for pulpwood would decline from 142 million m^3 to 90 million m^3. In contrast, the EUwood study projects this to increase to 200 million m^3. That is, if the markets would behave in the coming 17 years as they have on average in the past 10 years, the pulpwood consumption would be *110 Mm^3 lower* in 2030 compared to what the EUwood study projects.

The lower paper consumption and production would have many impacts for the EU wood balance. First, the demand for paper, pulp and pulpwood will be significantly lower than what EUwood study projects. By reducing the demand for pulpwood, it tends to lower the price of pulpwood (ceteris paribus), and therefore, lowering the costs to bioenergy producers. However, by reducing the pulpwood demand, it also reduces the forest residues generation, and tall oil production in pulp mills, both of which could be used for bioenergy production. Pulp mills are significant producers of bioenergy in EU, and if their production declines, so will also their bioenergy production. For example, in the EUwood study, energy generation from pulp process (black liquor) is expected in scenario A1 to increase from 60 million m³ solid wood equivalents in 2010 to 66 million m³ in 2020 and 85 million m³ in 2030 (67 and 72 million m³ in scenario B2). The net impacts of these factors can be either positive or negative for bioenergy production.

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[18] In 2011, about 75 percent of the EU total pulp consumption was chemical pulp (wood utilisation multiplier for coniferous pulp is 5.5 m^3/t, for hardwood pulp it is 4.2 m^3/t), and 25 percent was mechanical pulp (wood utilisation multiplier for mechanical pulp is 2.8 m^3/t). Assuming multiplier 5 for chemical pulp (most of this pulp is based on coniferous pulpwood), and 2.8 for mechanical pulp, the average multiplier is 0.75*5 + 0.25*2.8 = 4.45. However, typically, about 33 percent of the total wood pulp consumed in EU is imported from outside EU, so we here simply assume that the impact to EU pulpwood demand would similarly be 33 percent lower.
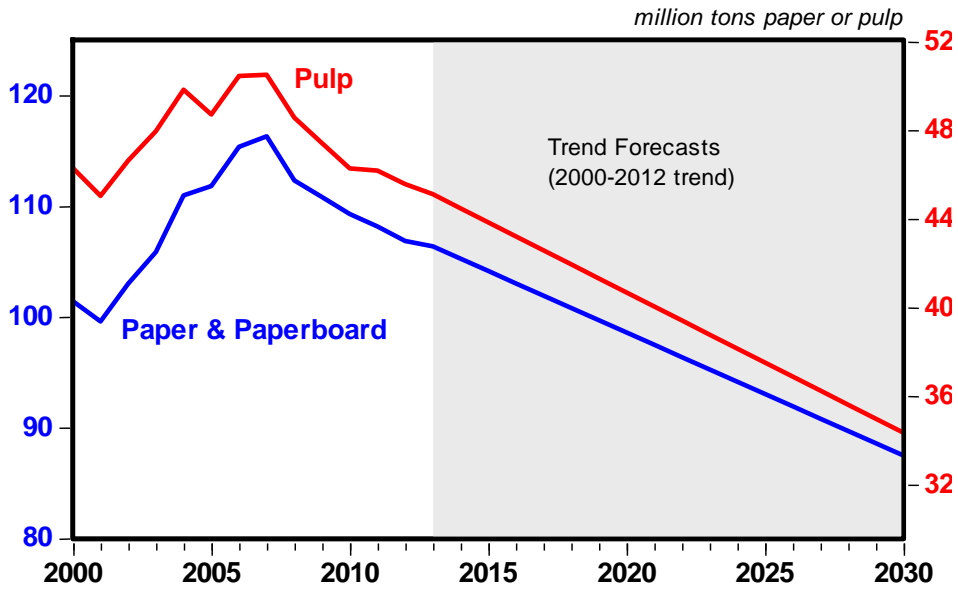
Figure 3.12 European Pulp and Paper & Paperboard 2000-2012 and Forecasts to 2030.
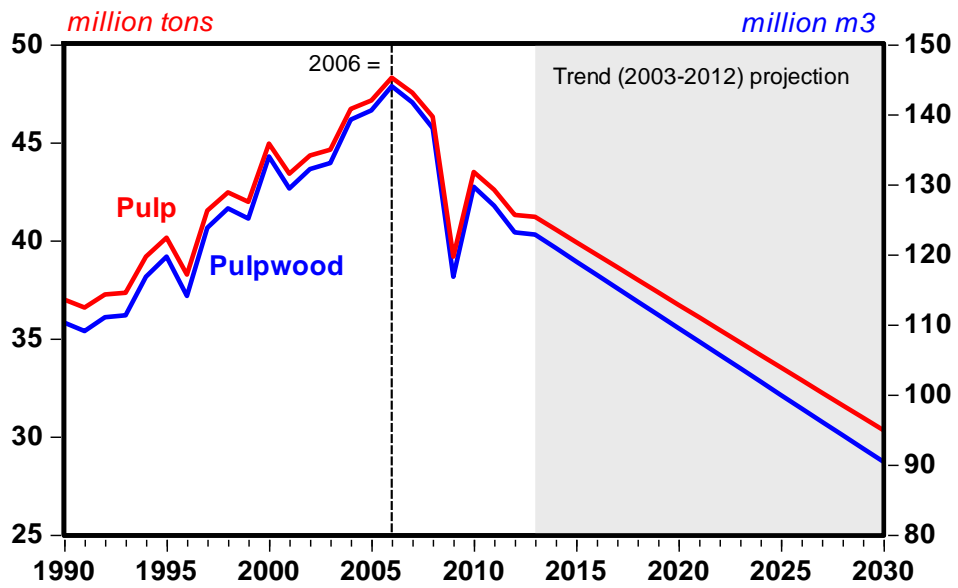
Figure 3.13 EU Woodpulp and Pulpwood Consumption in 1990–2012 and Trend Projection to 2030.[19]

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[19] P = preliminary data for 2012; TP = trend projection based on the last 10 years, i.e., 2003–2012 trend; EUwood = Mantau et al. (2010) projection. *Mantau et al. 2010 do not report these figures as such. However, the study reports the wood demand increase by sawnwood, pulp sector, and for the material uses from 2010 to 2030; these increases in demand are 25.6, 39.7 and 35.3 percent, respectively. We have made a simple

It should be noted that in the future, the pulp production does not necessarily decline exactly in line with the decline in fine (woodfree) paper production.[20] First, the EU countries can export more softwood pulp (probably not hardwood pulp, due to competition from South America and Asia). Secondly, some of the old "paper pulp" plants can be transformed to produce dissolving pulp for textile industries, as is already taking place e.g. in some plants in Finland and Sweden. Moreover, some pulp plants may start to produce only energy, such as gas (e.g. Joutseno pulp mill in Finland is planning to start to do this for the city of Helsinki). However, despite these possibilities, it is very likely that these factors will not be of important magnitude for many reasons, and there will be significant decline in pulp production in EU along with graphics paper consumption.

3.2.7 Comparison of the Projections to 2030

In recent years, there has actually been very little research on pulp and paper markets long term outlook. It is not a popular topic amongst academic researchers. Most of the outlook studies for the industry are published by consulting companies, which also tend to follow more systematically and in more detail the market developments. Here, we summarize the most well-known recent outlook studies for Europe by forest economists and consulting companies, and compare them to our own assessments. The studies analysed are the extensively cited EFSOS II (UN-ECE/FAO 2011) and Buongiorno et al. (2012) studies, and the RISI (2013b) consulting company study. Tables 3.6–3.8 summarise the main quantitative results of the projections at the European level.

The EFSOS II study does not actually provide data for pulp consumption and production projections to 2030. However, here we have assumed that they increase along the EFSOS II paper and paperboard production and consumption, i.e. 26 percent and 19 percent respectively. Buongiorno et al. (2012) provide four different scenarios, and the Table 3.8 shows scale of these scenarios. The Trend Forecast in Table 3.8. was based on data from 2005-2012. However, since year 2009 was exceptional slump year, the value for this year was replaced by the average of 2008 and 2010 values. If the actual 2009 value had been used instead, the trend projection would show lower consumption and production for 2030. The Forecast Model in Table 3.8. is based on using paper & paperboard production as an explanatory variable for pulp production. It actually tracks and explains very well the changes in the past pulp production (we tested this also by computing out-of-sample forecasts). However, this does not necessarily mean that it will be as good in explaining

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assumption in this Figure, that this demand is reflected in an equal percentage increase in end product demand from 2010 to 2030.

[20] The mechanical pulp production is likely to decline in line with the mechanical paper production decline.

the future pulp production. This is due to the fact that pulp mill production may in the future be increasingly used also for textile industry (dissolving pulp) and energy purposes, and not only for paper.

The most striking result is that the data from 21st Century, the forecasts of this study, and the RISI (2013 a) projections indicate very different projections than the EFOS II (UN-ECE/FAO 2011) and Buongiorno et al. (2012) studies. Moreover, the analysis of this study indicates that it is unlikely that the market structures and trends from the 20th Century will continue in this Century. Basically, there are strong arguments indicating that EFOS II and Buongiorno et al. may overestimate significantly the European paper consumption and production up to 2030. The projections from this study indicate that the European paper and paperboard production could decline from the 2010 level of 106 Mt, to 87 by 2030 (-19 m.t.). EFSOS II and Buongiorno et al. would instead project an increase of 25–45 Mt.

In line with the above projections, also the pulp consumption and production projections for 2030 differ significantly. According to this study, the European pulp consumption and production would be in 2030 about 20–30 Mt less than EFSOS II or Buongiorno et al. projects. This would, in turn, imply approximately over 100 million cubic meters less pulpwood demand.

The projections of this study are of course only one possibility, and unlikely to realize as such. However, they main message they communicate is that the forest industry and forest biomass based bioenergy industry should seriously assess the possibility of a very different scenario than the EFOS II and Buongiorno et al. suggest. The markets may decline instead of growing.

Table 3.6 European Paper and Paperboard Consumption and Production in 2010 and Projections to 2030

In million tons	Actual 2010	EFSOS II (2011) 2030	Buongiorno et al. (2012) 2030[1]	Trend Forecast *2005-2012 trend* 2030
Consumption	94	112	113 - 128	**93**
Production	106	134	131- 151	**87**

Table 3.7 RISI (2013a) Projections for European Graphics Paper Consumption and Production in 2010 and Projections to 2028[21]

In million tons	Actual Europe 2010	Western Europe 2030	Rest of Europe 2030[1]	Total Europe 2028	Europe 2028 vs 2010
Consumption	37.8	17	10.8	27.8	**-10.0**
Production	46.6	24.3	10.4	34.7	**-11.9**

Table 3.8 European Pulp Consumption and Production in 2010 and Projections to 2030

In million tons	Actual 2010	EFSOS II (2011) 2030[1]	Buongiorno et al. (2012) 2030[2]	Trend Forecast 2005-2012 trend 2030	Forecast Model
Consumption	52	62	55 - 67	**33**	
Production	46	58	53 - 64	**33**	**34**

3.2.8 Implications to Bioenergy Markets and Critical Questions

How would the above global and European pulp and paper market outlook impact the possibilities of forest biomass based bioenergy development? What are the critical questions it raises in terms of future bioenergy market developments in Europe?

First, the paper industry's production stagnation or decline specifically in Western Europe, North America and Japan will reduce the demand for pulp and pulpwood in Europe as whole. However, there will be regional differences, and in some Eastern European countries there could still be an increase in pulp production (e.g. Estonia, Poland). The net effect of this development for European forest biomass based bioenergy production is not clear, due to partly offsetting impacts.

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[21] Graphics paper share of total European paper & paperboard production in 2010 was 44 %.

First, pulp plants are also major energy producers, e.g. for district heating and paper industry. Declining pulp production will therefore also decrease this type of energy production. Secondly, the synergy and profitability gains achieved in forest biorefinery bioenergy production would be reduced. For example, the second generation biofuel production in an integrated pulp and paper mill would most likely not be attractive without the paper and pulp production. Thirdly, the procurement of pulpwood for pulp production also generates forest chips for energy production. Moreover, the income from pulpwood mobilizes forest owners to supply forest biomass to markets. Thus, many of the impacts of declining pulp production will have negative impact for forest biomass based bioenergy outlook in Europe.

On the other hand, reduced pulp production also reduces the demand and competition of forest biomass. This would tend to improve the possibilities and profitability for forest biomass based bioenergy production, for example, in the energy industry.

The possibility of declining pulp production in Europe, and its impacts to forest biomass based bionergy outlook in Europe, have not really been addressed in research. Given the above considerations, it would be important to provide a more detailed analysis of the many impacts of possibly declining pulp production for bionergy development in Europe. Also, the regional differences in the development should be addressed. Finally, scenarios of the non-paper based pulp production outlook in Europe should be carried out. In particular, what are the outlooks for dissolving pulp and pulp mill based energy production in Europe?

The new research results will take their time, but the companies need to act already now. The most important message is that the companies should be prepared in their strategies also for the possibility of the declining European pulp production.

3.3 Wood Products Markets

3.3.1 Introduction

3.3.1.1 Background and Scope of the Analysis

The wood products industry is very heterogeneous and fragmented, compared to for example the pulp and paper industry. The wood products industry consists of three main sub-markets, i.e. sawnwood, secondary processed products, and wood-based panels (see, Figure 3.14). In terms of the implications for bioenergy availability, the sawnwood industry and the plywood industry are the most significant sectors, while especially the particle board sector competes from the same raw material as bioenergy production. Due to issues with data quality and availability, the small volumes of secondary processed

products and furniture (see, Pahkasalo et al. 2013), and the significance of the sawnwood sector in the by-product flows for energy production and other forest-based industries (incl. wood-based panels), this analysis is focused on the global sawnwood markets. While the emphasis of the analysis is on Europe, global sawnwood trends and the most significant markets outside Europe are also considered.

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┌─────────────────────────────────────────────────────────────┐
│          Wood Products Industry (excl. furniture)           │
└─────────────────────────────────────────────────────────────┘
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SAWNWOOD	SECONDARY PROCESSED PRODUCTS	WOOD-BASED PANELS

• Unmodified
• Modified
  o mechanically
  o chemically
	• Joinery/carpentry
	• Profiled wood
	• Engineered Wood Products (incl. e.g. glulam, I-beams, LVL)
	• Wood composites
		• Veneer sheets
		• Plywood
		• Particle board (incl. OSB)
		• Fibre board (incl. MDF)
		• Other
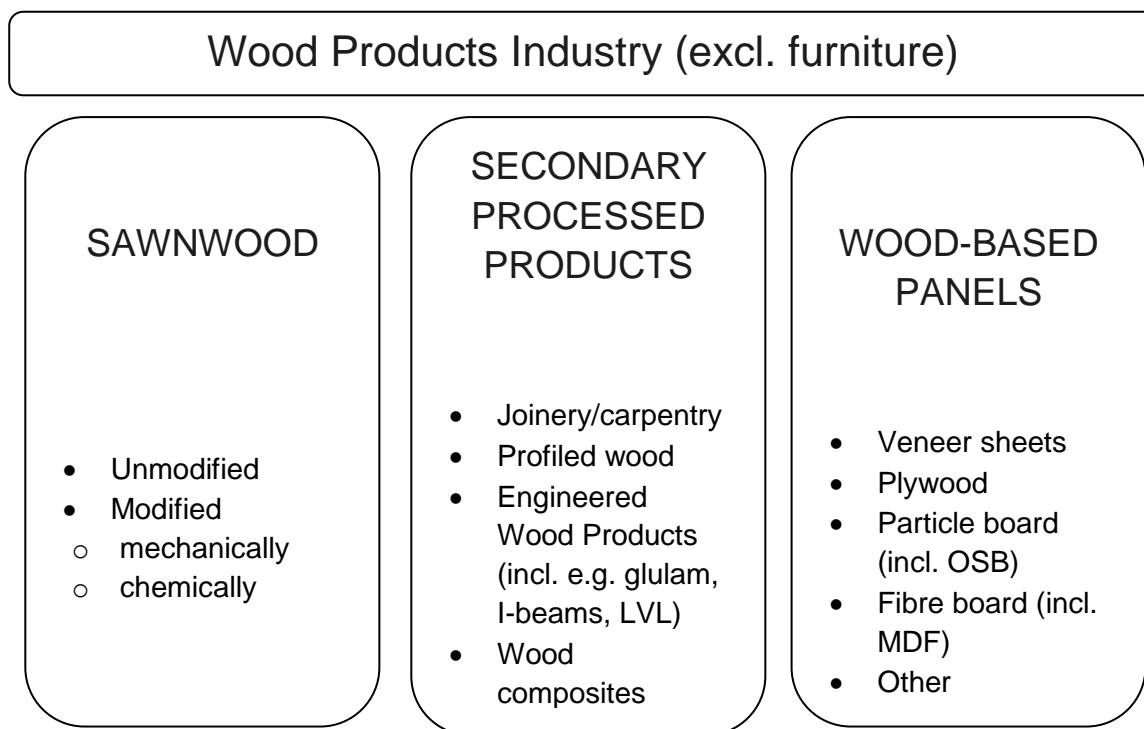
Figure 3.14 The Main Product Groups of the Woodworking Industry (excl. furniture).

The global production of sawnwood was 411 Mm^3 in 2012, corresponding to more than half of the total industrial roundwood use (Faostat 2013). Industrial roundwood for sawmilling provides the vast majority of the forest owners' income, and the developments of the sawnwood markets thereby largely determine the roundwood prices and supply flows for all the forest-based industries (pulp and paper, wood panels, and energy) (Lundmark 2007). The energy sector uses the slash, stumps, and small wood left over from industrial loggings and the wood chips, saw dust, and bark left over from sawmilling. The energy sector also increasingly competes from the same raw material as the pulp and wood-based panel industry, and the increasing demand for biomass for energy has already created significant price pressure for wood chips (Aguilar et al. 2013). Therefore, the wood products market development also clearly affects the prospects of the energy sector and has links to climate and energy policies. As a result of the energy policies favoring renewable resources and biomass, the wood products industry may have

increasing opportunities in refining energy products to be sold to the markets by its own as well.

3.3.1.2 Global Sawnwood Markets

North-America, the EU, and Asia account for 75 percent of the production and 80 percent of consumption in the global sawnwood markets (Faostat 2013). The sawnwood markets are largely dominated by coniferous sawnwood in Europe and North-America (91 and 84 percent of production, respectively). Production of tropical sawnwood in the world (Asia-Pacific, Latin America/Caribbean and Africa) totalled 42.7 Mm^3 in 2011 (ITTO 2012). However, these markets are out of the scope of the following analysis, as tropical sawnwood imports by EU-27 countries are very minor, around one million m^3 annually, in large contrast to Asia.

As the construction sector largely profiles the demand for sawnwood, the demand shifters are generally linked to population growth, household size, and general economic activity. The European sawnwood markets have seen relatively few major changes over the past decades. They have on an average been following population growth and business cycles of the construction sector (Faostat 2013). There are few exceptions to this sluggish growth trend. The most significant one was when the USSR ceased to exist in 1991, resulting in a sudden plummet in the sawnwood supply from Eastern Europe. As a reaction to this institutional change, the markets in the EU started to grow faster compared to the period of 1960 to 1990. However, the lengthened financial crisis that started in 2008 and the resulting low demand for new construction has kept the demand for sawnwood well below the pre-crisis levels in the recent years.

3.3.1.3 Objectives

Despite the relevance of wood products markets for the material flows of the whole forest sector, long-term outlook studies focusing on wood products markets appear to be rare. The objective of this chapter is to analyse the current state and the possible future developments of the global sawnwood markets. The analysis aims to contribute to defining the implications of the recent and prospective forest sector market trends in terms of the forest bioenergy potential.

The chapter is structured as follows. First, we briefly summarise some of the most recent outlook studies for the wood products industry, with an emphasis on coniferous sawnwood in Europe (incl. Russia), North-America, and Asia. Second, we produce trend forecasts based on the most recent data (Faostat 2013), and compare them to the summarised outlook publications. Third, we discuss the validity of the projections and the prospects of possible future structural changes in the wood products markets. Next, we produce simple

"what if" scenarios for the sawnwood markets and discuss the implications to the wood chip availability and bioenergy production in Europe. Finally, we draw conclusions from the analysis and summarise the critical uncertainties related to the wood products market development.

3.3.2 Methods and Data

The methodology consists of a literature review, trend analysis, and scenario analysis. In the literature review, the sawnwood market prospects for Europe, North-America, and Asia are summarised based on the most recent regional outlook studies, provided by e.g. UNECE/FAO.

The trend projections were carried out using a simple linear forecast function. The trend analysis aims to provide baseline scenarios, against which different future developments can be mirrored. The trend projections are also compared to the projections of UNECE/FAO (2011).The wood-based panel production in Europe is also briefly discussed, as it could have an effect on the industrial residue prices and availability on a more general level.

The scenario analysis follows the Trend Impact Analysis approach (see, Gordon 2009), in which we have historical trends as a basis and assume different possible growth rates in future. We make assumptions on the population and consumption per capita developments to 2050, but do not consider in detail, how they could be achieved or whether it seems likely. The approach to the 'what if' –scenarios is very similar to Hänninen (2009), i.e. we assume three trend scenarios and one structural change scenario, and briefly discuss their possible implications and compare the scenario outcomes to prior qualitative information.

The results are only very suggestive, due to many uncertainties and oversimplifications. Also, the implications of the scenarios for the bioenergy production and by-product availability appear difficult to determine precisely. As a result, only an approximate quantitative estimate for the implications for the by-product availability and for the bioenergy production is given, while the emphasis of the analysis is on discussing the critical factors affecting the future volume of the sawnwood production and consumption.

The statistical data is based on Faostat (2013) database, unless otherwise specified. The forecasts in section 3 are taken from the background documents of recent outlook studies. The calculations regarding the implications of the scenario analysis for the bioenergy production are based on unofficial statistics and simplifying assumptions (e.g. Mantau 2012, Keränen and Alakangas 2013).

3.3.3 Summary of Global Wood Products Markets Outlook Studies

This section summarises the most recent market reviews and long-term outlook studies for wood products markets. The focus is on sawnwood markets, but the demand patterns are similar also for structural panels (e.g. OSB and plywood) and for non-structural panels (MDF and particle board), i.e. they are all dependent on housing starts and general economic activity.

The sawnwood markets are characteristically very cyclical. Much of the cycles are explained by the fluctuations in the main demand determinant for sawnwood, i.e. construction activity (see, Figure 3.15). Even though large fluctuations are not unusual in the construction markets, the current slump in housing starts appears to be exceptionally severe and long-lasting in the historical context. The housing starts in the US were as low as currently last time in the 1940's (US Census Bureau 2014). A recession this severe is very likely to have also consequences for the long-term prospects of the sawnwood markets, and may also affect the industry structure. Most of the recent outlook studies have not considered the latest economic downturn, i.e. their base year of analysis is prior to the most notable effects of the crisis.
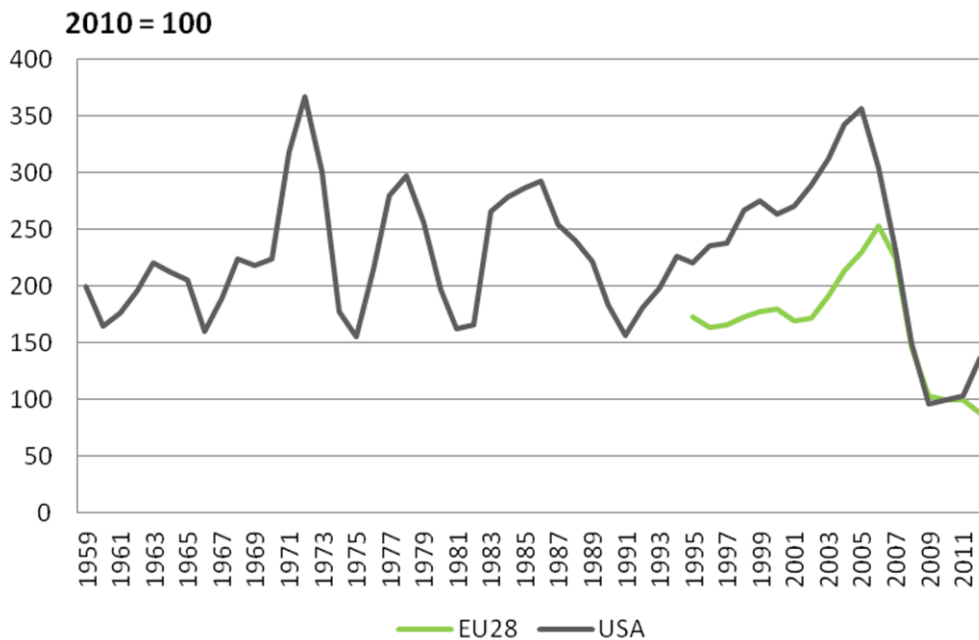

Figure 3.15 Historical Housing Starts in EU28 and USA (Eurostat 2013, US Census Bureau 2013).

3.3.3.1 Europe (incl. Russia)

The reference scenario of UNECE/FAO (2011) suggests that the consumption of wood-based products in Europe would increase only slightly, by 2–8 percent by 2030 (see, Table 3.9). In contrast, the consumption of wood-based energy is projected to increase by 35 percent. Moreover, according to Mantau et al. (2010a), the policy targets for bioenergy would translate into more than doubling demand for energy wood by 2020. Also, according to Jessup and Walkiewicz (2013), it appears that wood demand for energy use will overtake wood demand for other, non-energy use by 2020. If the strong growth scenarios for wood energy demand would realise, trade-offs between different uses could possibly arise. The outcomes for European markets would depend on for example international trade in forest biomass and market adjustments, and the technical efficiency of the bioenergy production process. The increase in the price of wood and wood products is expected to be steady and moderate. Europe is projected to remain a net exporter of forest products in all scenarios.

Compared to the other three major regions (Europe, North America, Asia), Russian sawnwood market is a big question mark. The sawnwood production in the former USSR was on average almost four times higher than the current production in Russia (Faostat 2013). However, the production in Russia has been increasing in the recent years from the level of 20 Mm^3 in 2000 to 32 Mm^3 in 2012. Yet a large share of the production capacity is old and inefficient and so far there has not been strong push for increasing or renewing the sawnwood capacity. Nevertheless, it is important to note that the sawnwood production in Russia has already by 2007 exceeded the reference scenario forecast to 2030 by UNECE/FAO (2011). In this sense, the FAO (2012) projections that anticipate a significant growth of sawnwood production in Russia, by over 10 Mm^3 by 2030 even according to the lowest scenario, seem reasonable in the light of recent trends (see, Table 3.10). However, according to FAO (2012), measures on the following factors would be needed to ensure the sawnwood industry development: Transition from worn-out sawmilling to new technologies, increase in non-coniferous sawnwood, increase in the share of sawnwood with normative humidity, switch to certified production, increase in modern high-quality products and materials, and increased use of sawmilling waste for the manufacturing of wood composite materials and bioenergy.

In Russia, the measures for attracting investments for the ageing equipment and infrastructure have previously been based on restrictions such as roundwood export tariffs (Indufor 2013). However, measures that aim to facilitate making investments, such as Russia's WTO accession in 2012, may provide better possibilities for achieving this end in the long-run.

In the joinery and furniture industries, the European producers are under severe cost pressure from China and other Far East countries, where the growth in production has been rather explosive (Wahl 2008). In addition to the increased competition in export markets, the imports to Europe have also significantly increased. With the increased price

competition, hardwood processing capacity is gradually shifting from the Western Europe to Eastern Europe.

Table 3.9 EFSOS II Reference Scenarios (IPCC B2) for the Most Important European Producer and Consumer Regions of Wood Products (Jonsson 2012).

	Sawnwood production (Mm³ RWE)						*Sawnwood consumption (Mm³ RWE)*					
	2007	2010	2015	2020	2025	2030	2007	2010	2015	2020	2025	2030
Finland	12.5	12.9	13.3	13.6	13.9	14.1	6.0	5.7	5.9	6.2	6.4	6.5
Austria	11.3	11.0	11.2	11.5	11.7	11.9	5.1	5.4	5.4	5.5	5.5	5.6
France	10.2	9.9	10.0	10.2	10.3	10.5	13.3	12.4	12.5	12.6	12.6	12.7
Germany	25.2	21.8	22.7	23.6	24.2	25.0	19.8	19.3	19.3	19.4	19.4	19.5
Italy	1.7	1.6	1.7	1.7	1.7	1.7	9.3	9.0	9.4	9.8	10.1	10.4
Netherlands	0.3	0.3	0.3	0.3	0.3	0.3	3.1	3.1	3.1	3.1	3.0	3.0
Spain	3.3	3.7	3.7	3.7	3.7	3.8	7.2	7.2	7.3	7.4	7.5	7.6
Sweden	18.6	17.7	17.8	18.0	18.1	18.3	7.7	6.3	6.4	6.6	6.7	6.7
the UK	3.1	2.9	2.9	2.9	2.9	2.9	11.2	10.9	10.8	10.8	10.6	10.7
Total Europe (excl. Russia)	**132.4**	**127.4**	**131.0**	**135.0**	**138.2**	**142.6**	**125.9**	**121.0**	**123.7**	**126.7**	**129.5**	**133.3**
Russia	23.2	22.9	24.1	25.4	27.1	29.4	5.9	8.0	8.5	9.0	9.6	10.5
	Wood-based panel production (Mm³ RWE)						*Wood-based panel consumption (Mm³ RWE)*					
	2007	2010	2015	2020	2025	2030	2007	2010	2015	2020	2025	2030
Finland	2.0	2.0	2.2	2.3	2.3	2.3	0.9	0.8	0.8	0.8	0.8	0.9
Austria	3.7	3.5	3.6	3.8	3.8	3.9	1.0	1.5	1.5	1.6	1.6	1.6
France	6.7	6.4	6.7	7.0	7.2	7.5	5.4	5.0	5.1	5.3	5.3	5.4
Germany	18.2	16.8	17.5	18.3	18.4	19.0	16.0	14.1	14.7	15.4	15.7	16.2
Italy	5.7	5.5	5.8	6.1	6.2	6.4	7.1	6.6	7.0	7.4	7.5	7.8
Netherlands	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.6	1.7	1.7	1.7	1.8
Spain	5.4	5.2	5.6	6.0	6.2	6.5	5.3	5.4	5.8	6.1	6.3	6.5
Sweden	0.9	0.8	0.9	0.9	0.9	0.9	1.2	1.3	1.4	1.5	1.5	1.5
the UK	3.5	3.5	3.6	3.7	3.8	3.9	6.9	6.8	7.1	7.4	7.5	7.7
Total Europe (excl. Russia)	**79.4**	**74.5**	**78.6**	**83.2**	**85.9**	**90.8**	**78.0**	**73.2**	**77.1**	**81.4**	**84.6**	**89.5**
Russia	9.8	8.7	9.4	10.1	11.2	12.9	9.0	7.9	8.6	9.3	10.5	12.1

Table 3.10 Alternative Developments for the Russian Sawnwood Industry According to the Scenarios by FAO (2012).

	2010	2015	2020	2025	2030
Production					
Innovation	24.7	42.0	55.0	59.5	66.2
Moderate	24.7	35.8	43.4	47.0	51.5
Inertial	24.7	29.6	31.7	34.4	36.8
Export					
Innovation	17.7	18.6	21.1	22.6	26.3
Moderate	17.7	19.0	19.9	22.4	24.9
Inertial	17.7	19.5	20.8	22.8	24.5
Consumption					
Innovation	7.1	23.5	34.0	37.0	40.0
Moderate	7.1	16.9	23.6	24.7	26.7
Inertial	7.1	10.2	11.0	11.7	12.4

According to UNECE/FAO (2011), sawnwood residues constitute around 10 percent of total wood supply in Northern and Central Europe. Given the sluggish growth trends of the sawnwood markets, the share is not seen to grow significantly towards 2030. The supply growth for forest energy is seen to come mainly from stumps, harvest residues (incl. thinnings), landscape care wood, and postconsumer wood (recovered wood). Based on the UNECE/FAO (2011) baseline scenario, the production and consumption of wood-based panels would also be increasing in Europe, thereby increasing competition of the woodchips produced in sawmilling as a side product.

3.3.3.2 North America

UNECE/FAO (2012) assumes that the markets for wood products in North-America will recover from the housing market decline by 2015. According to a high economy growth scenario, the sawnwood markets are expected to double from 60 Mm^3 in 2010 to 120 Mm^3 in 2030 in the US (long term average 80 million), after which the production would start to decline again. However, in Canada, the sawnwood output is expected to remain at the

2010 level (35 Mm^3) until 2030, even though the production peaked in 2005 at 60 Mm^3, due to declining domestic demand. The US is seen to remain a net importer of sawnwood (domestic demand grows and exports decrease), and Canada would further increase its exports to the US (Buongiorno et al. 2012, McCusker et al. 2012, UNECE/FAO 2012).

UNECE/FAO (2012) suggests huge growth in the bioenergy markets in North America. The production of bioenergy is forecast to increase from 50 Mm^3 in 2010 to 200 Mm^3 by 2030. However, the growth in the use of woody biomass for energy is seen to significantly influence the sawnwood markets only near 2030. Until then, the prices for most forest products (including sawnwood) are expected to trend downwards, unlike what e.g. Taylor et al. (2013) suggest.

3.3.3.3 Asia

The Asian markets seem to have been rather unaffected by the recession in the Western markets. However, according to IWMG (2012), the demand for sawnwood in China slowed during 2011 and 2012 after a few years period of very strong increase, following the same trend in the housing markets. Coniferous sawnwood consumption would therefore remain at around 30 Mm^3. Even if the strong growth would not continue as such, China would still hold its place as one of the most significant sawnwood markets globally.

In Japan, the housing markets have been facing a downward trend already for decades, which has resulted in a similar trend also in the sawnwood markets. The housing starts peaked in the 1980s at 1.7 million, from where they have declined to the current level of 0.8 million. According to IWMG (2012), there are no prospects for strong recovery from the 1990s recession that has continued to the present day, due to e.g. ageing population and near zero population growth. However, there might be some slow recovery in the housing markets driven by e.g. the reconstruction work required after major earthquakes and tsunamis. Also, Japan has set monetary subsidies and other incentives to increase the rate of self-sufficiency in sawnwood consumption from 30 to 50 percent by 2015, which could affect the imports (IWMG 2013). Therefore, it would be more plausible to assume the Japanese wood products markets to stay at the level of recent years, rather than to continue to decline substantially.

3.3.3.4 Summary of Outlook Studies

According to IWMG (2012), the global coniferous sawnwood markets are expected to grow very modestly in the following years. The only market that is seen to grow (recover to the pre-crisis levels) in a significant scale would be the USA. A "super-cycle" of elevated sawnwood prices in North America, driven by tightening Canadian and Russian timber

supplies and strong growth in the US (and Chinese) demand, is expected to occur after 2015, if the recovery from the financial crisis achieves full pace (Taylor et al. 2013).

There are only few global long-term outlook studies for sawnwood markets available. One of them, Buongiorno et al. (2012), suggests that North-America would remain the world's largest consumer of sawnwood for the whole 21st century, and Asia would take Europe's place as the world's second largest consumer only towards 2045. However, these projections towards 2060 were outdated already at the time of publishing, as the consumption in these three regions was on the exact same level already in 2008 and the roles of Asia and North America have interchanged since then (Faostat 2013).

In general, it is not the objective of outlook studies to predict the future levels of consumption, but rather to study the consequences of certain possible market trends or policy choices. Therefore, the main conclusions of Buongiorno et al. (2012) may still be indicative, even though the projections would be largely outdated. They conclude that according to a strong economic growth scenario, the global consumption of wood fuel would grow more than five times by 2060, which would lead to a rapid growth of real prices for fuel wood which would converge with the real price of industrial roundwood by around 2030, having strong effects on the whole forest products markets (most notably wood-based panels and the pulp and paper industry, and possibly new wood-based products and services).

3.3.4 Sawnwood Trend Projections to 2030

In the following, we present simple trend projections for the sawnwood and wood-based panel markets, based on the most recent data from FAOSTAT (2013). The assumptions for the trends are kept the same for every market, i.e. "Trend 1" refers to the estimation period of 1992–2012, and "Trend 2" refers to the estimation period of 2000–2012. For comparison, the estimation period in UNECE/FAO (2011) is 1961–2007, so that those estimates give more weight on more distant observations and long-term trends, and do not include data of the more recent developments.

3.3.4.1 Sawnwood

Even though the financial crisis is to some extent considered in the EFSOS II projections, the reference scenario projection of UNECE/FAO (2011) appears rather optimistic from today's perspective. The production and consumption of sawnwood in Europe plummeted by nearly 30 Mm^3 from 2007 to 2009 and have not significantly recovered since then (Faostat 2013).

The growth rate of the sawnwood production in Europe suggested by UNECE/FAO (2011) is between Trend 1 and Trend 2, i.e. it suggests relatively slow growth (Figure 3.16). The

consumption is seen to grow in a similar manner, in line with Trend 1 (Figure 3.17). However, Trend 2 would suggest a remarkable decline in the European sawnwood consumption. When considering the steep decline in the previous five years, even the production would seem to hardly reach the 2007 peak level by 2030, not to say much above it.
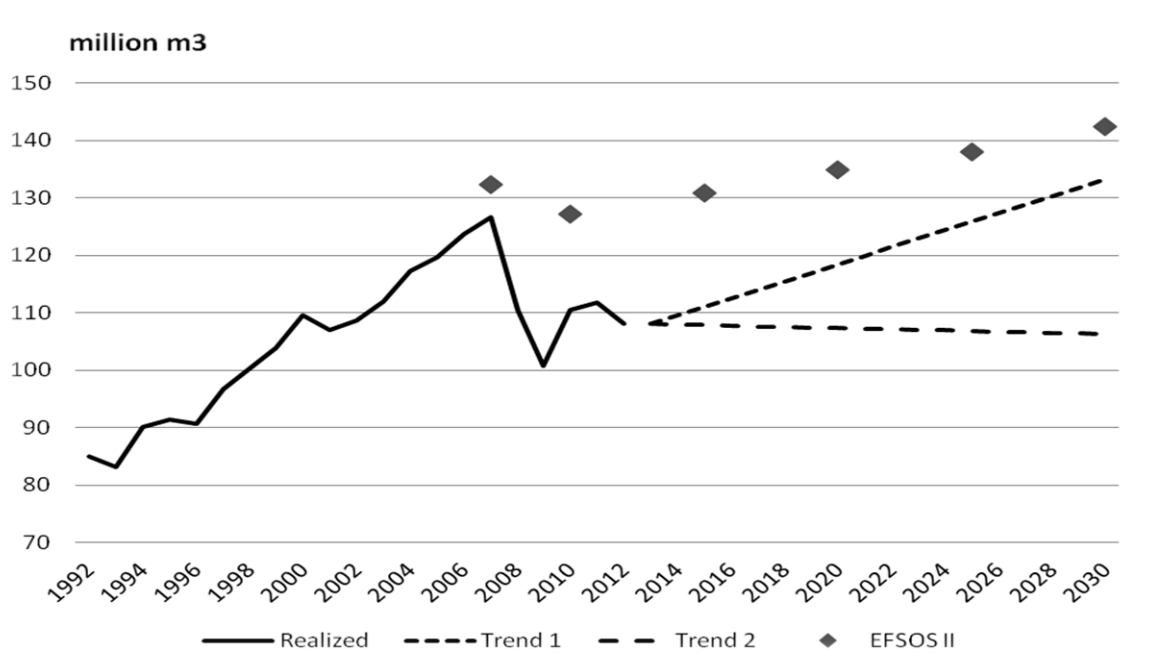

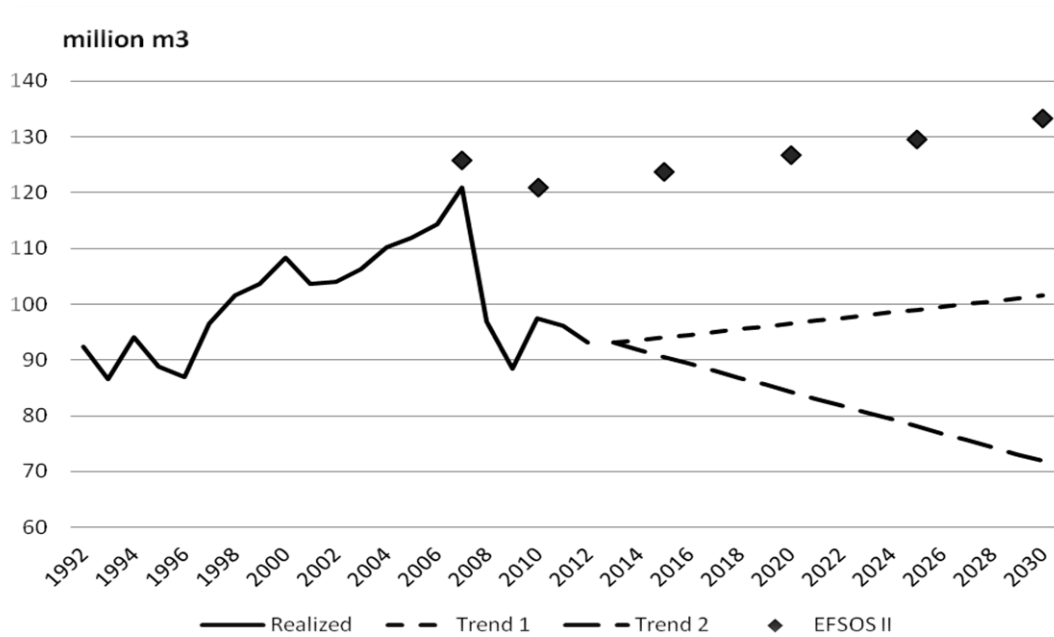**Figure 3.16** Sawnwood Production in Europe (excl. Russia).

Figure 3.17 Sawnwood Consumption in Europe (excl. Russia).

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In the global scale, by comparing the trend projections it seems that the production in Asia and North America and the consumption in Asia seem to be the most significant question marks for the following decades, while the sawnwood markets in Europe seem to remain comparatively stable, irrespective of the estimation period (Figure 3.18).
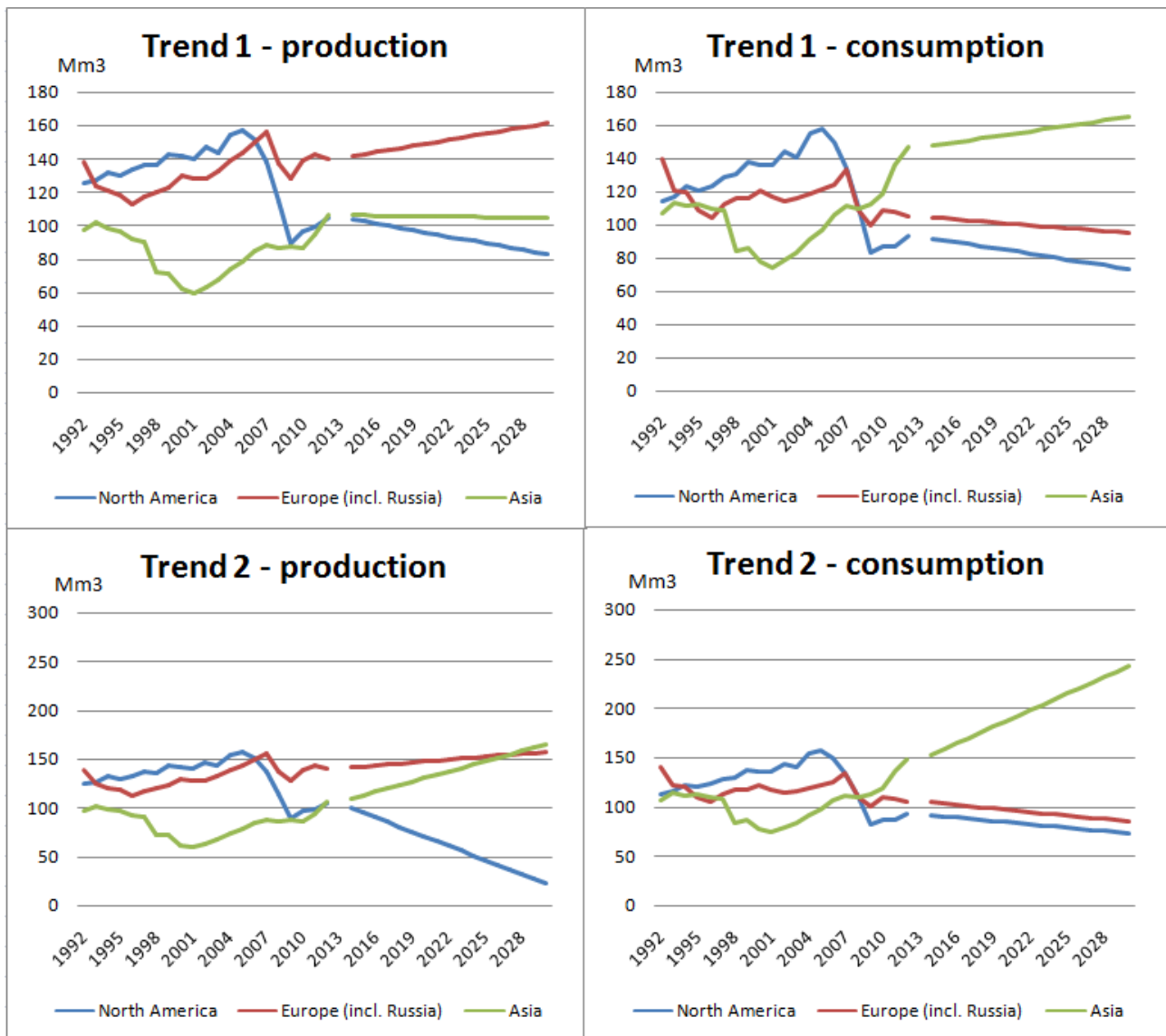

Figure 3.18 Global Sawnwood Market Trends (FAOSTAT 2013).

3.3.4.2 Wood-Based Panels

Both of the trend projections, and also the EFSOS II reference scenario show a growing trend for wood-based panel production in Europe (Figure 3.19). The growth in panel production has exceeded the growth rate of sawnwood remarkably, and based on these

projections the growth would continue, even though the level of wood-based panel production was also severely affected by the financial crisis. The trends would suggest increasing competition for the users of industrial wood residues, in line with the UNECE/FAO (2011) baseline scenario, where the relatively fast increasing production and consumption of wood-based panels imply increasing competition from woodchips.
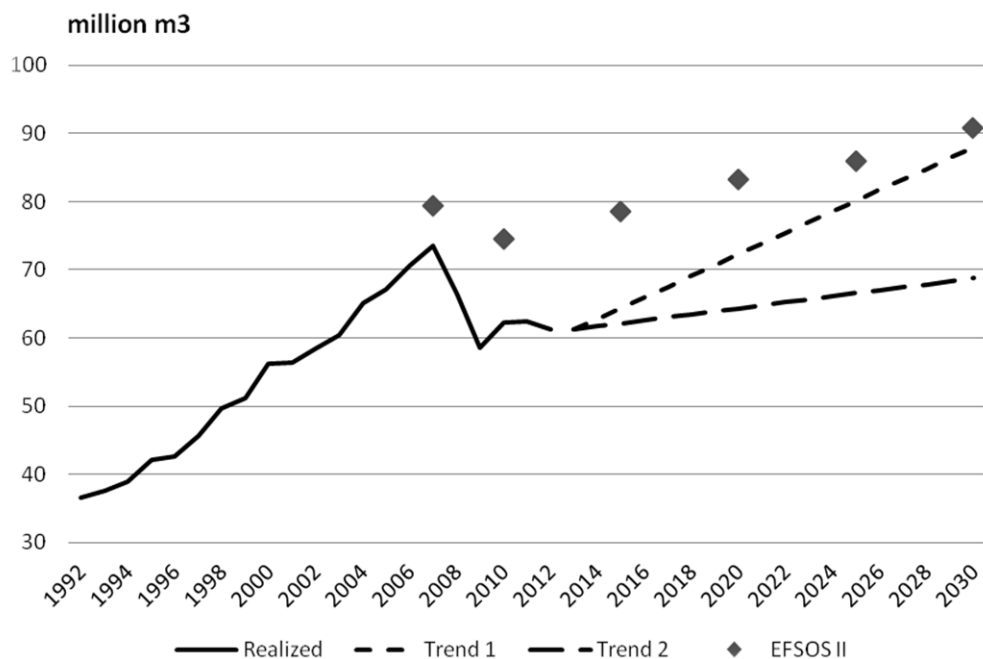
Figure 3.19 Wood-Based Panels Production in Europe (excl. Russia).

3.3.5 Validity of Projections and Prospects for Structural Changes

3.3.5.1 Validity of Projections

The trend projections can only serve as a basis for further analysis, as they only extrapolate the direction of the past trends as such for decades ahead, and may become outdated very quickly, as has happened to most of the studies synthesised above. For example, UNECE/FAO (2011) was unable to consider the severity of the financial crisis and its consequences. As a result, the sawnwood consumption projections are even tens of millions of cubic meters higher than the trend projections based on the latest available data. Consequently, there is a clear need to update the assessments on the long-term development of the wood products markets in Europe to consider the effects of the long-lasting weak financial situation.

Table 3.11 Factors Affecting the Volume of Sawnwood Industry.

	Business cycle factor (short-run)	Structural factor (long-run)

Factors determining overall demand for construction	Economy
	  Economic activity (GDP)
	  Prices
	  Interest rates
	Construction activity
	  New construction
	  Repair & remodelling
		Economy
		  Available income (GDP/capita)
		  Unemployment
		Housing
		  Size of households
		  Size of homes constructed
		Demography
		  Population
		  Urbanisation
		  Ageing

Factor of material substitution in the construction markets	Prices	Relative prices Raw material availability Traditions and culture Attitudes, awareness, preferences, etc. Policies, promotion, platforms, etc.

The demand estimates in the forest sector outlook studies are often based on prices and different assumptions on the GDP growth rate. In reducing the operational environment to the GDP growth and prices alone, the scenarios tend to overlook other affecting factors that could be significant in shaping the future direction of the markets. More specifically, the projections often consider only the general activity of the economy, and do not explicitly discuss the possibility of structural changes or substitution trends in the markets. However, the longer the time scale of analysis, the more important it is to also consider changes in market shares caused by factors unrelated to the general economic activity, such as ICT-development, advances in technology, and policies and regulations. Table 3.11 presents such a classification of the drivers of demand for sawnwood that makes a distinction between short-term cyclical and long-term structural factors on one hand, and between factors of total demand for markets (economic activity and demographics), and factors causing substitution in the markets (changes in market shares) on the other hand.

Added to the issues with the validity of methods and indicators for long-term outlook studies, there are also many issues with the reliability, relevance, and availability of data. The FAO statistics may be largely underestimated, even in a scale of tens of millions of cubic meters (cf. Chinese Academy of Forestry 2012).

3.3.5.2 Prospects for Structural Changes in the Wood Product Markets in Europe

Historical trends and major demographic and economic indicators do not seem to support strong growth for housing demand in Europe. That is, the number of inhabitants in Europe is projected to stagnate, while the population is rapidly ageing and urbanising towards 2030 (UN 2012, 2013). Moreover, the economic growth seems to be sluggish for the next decades (OECD 2012). It follows from these demographic and socio-economic trends that the increase in the use of wood in the long-run seems possible mainly through an increase in the *consumption per capita*. Therefore, the main interest in the long-term prospects for the European sawnwood markets culminates to the substitution between different materials in the construction markets, as opposed to the growth rate of economy.
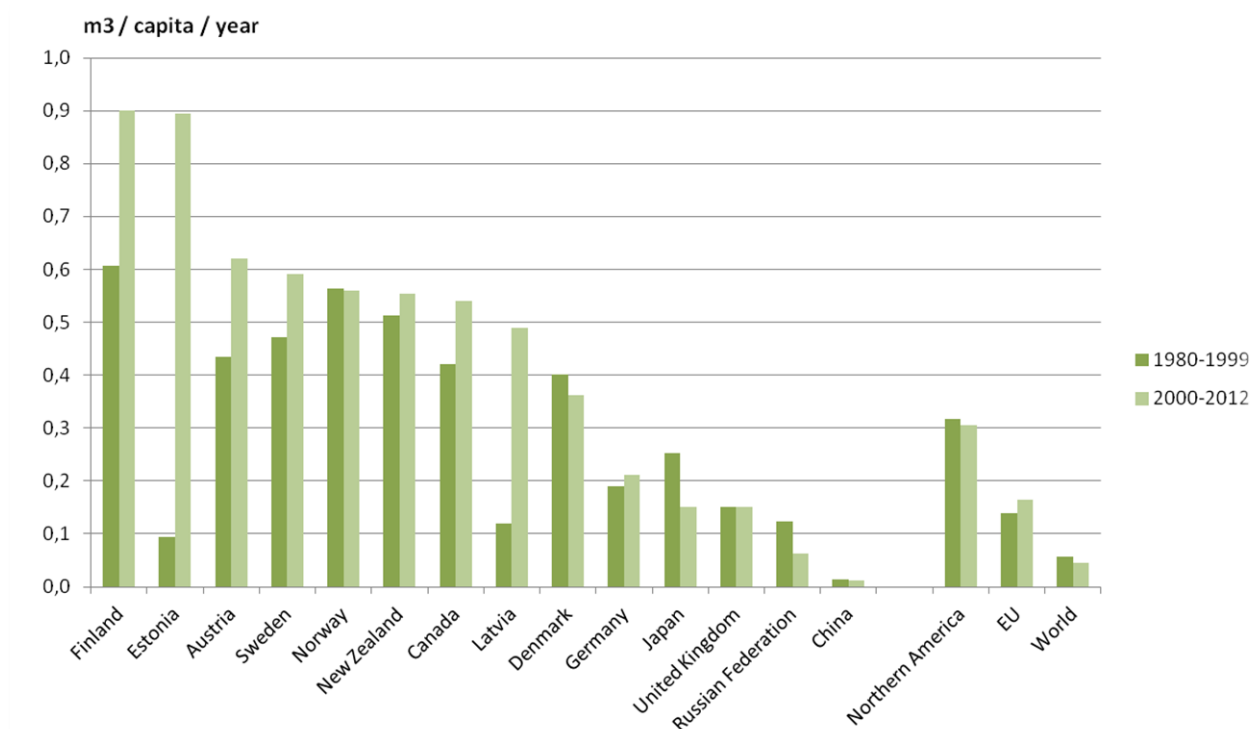
Figure 3.20 Consumption per capita for Coniferous Sawnwood in Selected Countries and Regions (Faostat 2013).

The construction markets have changed very slowly in the past, and there have been few changes away from the traditional building practices. Correspondingly, the consumption per capita figures suggest that there are large persisting regional differences in the construction markets (see, Figure 3.20). However, major structural changes have indeed also occurred, although only on a national level and not in the aggregate statistics. It seems that while most of the modest increase in the sawnwood consumption per capita could be explained by economic growth, the exceptionally large increases in the

consumption per capita of sawnwood observed in certain regions could be due to promotion campaigns, driven by e.g. climate change mitigation and sustainability arguments. Instead of assuming the aggregate level trends to continue, it is important to ask, whether such changes could happen also elsewhere and in a larger scale.

The observed increase in the use of wood in construction in certain countries has occurred mainly in the low-rise residential construction sector. However, a recent trend has been a shift from on-site construction towards industrial prefabrication and multi-storey element systems that improve the efficiency and cost competitiveness of wood against other materials in the other sectors as well, i.e. in multi-storey and non-residential sectors (see, e.g. Kristof et al. 2008, Tekes 2011). In the wood products markets, the industrial prefabrication trend is still in its infancy, but the market potential for the concept is large, as in most countries the share of wood frame in multi-storey and non-residential buildings is fairly small. The success of the already completed projects and the approval of the general public of the ongoing and prospective experimental wood construction initiatives may largely determine, whether the industrial prefabrication of wood element systems will begin to follow a typical logistic S-growth curve of technology substitution.

There has been a lot of discussion on the need to increase the value-added of the wood products industry, as the strategy of reducing costs and improving technological efficiency of production for improving competitiveness is increasingly difficult, especially in countries of high unit costs. Engineered wood products and especially CLT-based element systems provide a good opportunity for achieving this end, as they require less wood per unit output and more knowledge-intensive services that produce value-added to the end product. In an extreme case, it would not make much difference in terms of the profits for the company or revenues for the country, where the elements would be produced, if the head quarter functions, education and consulting, patents and licenses, R&D, planning, engineering and programming, financing and insurance (incl. warranty), logistics, commissioning and maintenance, surveying and remodelling, demolition, recycling (partly as energy), and other expert services would be provided within a single country (e.g. Makkonen et al. 2013). However, this would require the current wood products producers to take steps towards acting as a construction company instead of being only a supplier of products.

3.3.6 What if Scenarios for Sawnwood Consumption per capita to 2050

3.3.6.1 Assumptions of the Scenario Analysis

The assumptions for the growth rates of sawnwood consumption are summarised as follows. The first two scenarios assume the consumption per capita to continue to develop according to the trends based on the same reference periods as in section 3.4, i.e. 1) Trend 1 (the period of 1992–2012), and 2) Trend 2 (the period of 2000–2012). The third scenario assumes that the consumption level 3) remains at the level of the 2007–2012

period average. Added to these trend scenarios, we finally assume a structural change scenario, where the average consumption per capita 4) doubles from the 2007–2012 period average level by 2030 and triples by 2050. Each scenario follows the middle fertility projections of the UN (2013) and assumes a constant market structure, competitive advantage, and operating environment. Holding other factors constant improves the comparability of the scenarios on one hand, but reduces the plausibility of the results as a downside. However, the purpose of the scenario analysis is not to predict the future levels of demand, but only to assess the possible implications of the scenarios, if they would be fulfilled.

The implications of the scenario analysis are given from two perspectives, namely, the sawnwood market balance and roundwood consumption in the EU, and the by-product availability and bioenergy production from sawmilling residues in Europe.

3.3.6.2 Implications for Sawnwood Market Balance and Roundwood Consumption in the EU

Table 3.12 presents the implications of the scenario analysis for the EU, in relation to the corresponding production trends. The production trends show a 60 Mm^3 difference towards 2050, depending on the assumption on the length of the estimation period, i.e. Trend 1 (1992–2012) versus Trend 2 (2000–2012). According to the production Trend 1, the Scenario 2 would imply an excess production of 125 Mm^3 in Europe that would have to be exported. In contrast, Scenario 4 would require imports of the exact same magnitude.

Scenarios 1 and 3 imply an excess production of 40–60 Mm^3. The production Trend 2 would imply more balanced markets in terms of supply and demand in the EU, with the exception of the structural change consumption scenario (scenario 4). In short, the effect of the financial crisis on sawnwood production and consumption reduces the estimates for the market gap, compared to the longer run trends.

According to Mantau (2012), the annual potential from forests available for wood supply in the EU27 is 713 M m³. In 2010, the removals corresponded to around 75 percent of the available potential, so that around 170 M m³ remains available sustainably. According to Verkerk et al. (2011), the realisable raw wood potential in the EU would be around 600 Mm^3 annually, considering e.g. ecological and technological constraints. For comparison, the wood use for sawnwood production in the EU was around 200 Mm^3 in 2012. With the exception of the structural change scenario (scenario 4), none of the projections would seem to significantly threaten the sustainable logging potential. The wood use in Scenario 4 (around 580 Mm^3) is already close to the total realisable raw wood potential, if the demand could not be satisfied by imports and it would not be restricted by rising prices.

Table 3.12 Synthesis of Apparent Net Trade (market imbalances) for Sawnwood Markets in the EU.

	2012	2030	2050
Population	503.4	516.1	511.9
Production (Mm^3)	97.7		
Production - Trend1		122.7	152.0
Production - Trend2		94.9	91.5
Wood use (Mm^3 RWE)	205.4		
Production - Trend1		257.8	319.4
Production - Trend2		199.4	192.3
Consumption per Capita (m^3/capita/a)	0.17		
Scenario 1		0.20	0.22
Scenario 2		0.12	0.05
Scenario 3		0.18	0.18
Scenario 4		0.36	0.54
Consumption (Mm^3)	84.7		
Scenario 1		105.1	110.4
Scenario 2		60.0	26.7
Scenario 3		93.2	92.5
Scenario 4		186.5	277.5
Apparent net trade (Mm^3) - Production Trend 1	13.0		
Scenario 1		17.5	41.6
Scenario 2		62.6	125.3
Scenario 3		29.4	59.5
Scenario 4		-63.8	-125.5
Apparent net trade (Mm^3) - Production Trend 2	13.0		
Scenario 1		-10.3	-18.9
Scenario 2		34.8	64.9
Scenario 3		1.6	-1.0
Scenario 4		-91.6	-186.0

3.2.6.3 Implications for By-Product Availability and Bioenergy Production from Sawmilling Residues in Europe

The by-product availability and bioenergy production implications follow the same pattern as the sawnwood production and consumption trends and scenarios. However, deriving accurate estimates for the implications is not straightforward, because statistics for this purpose appear to be rare. While statistics do exist on the total wood material flows (e.g. Mantau 2012, Keränen and Alakangas 2013), the input and output estimates for single sectors do not match, so that it cannot be inferred, which part of the input flow is converted into which product. This is due to trade, and more importantly, due to the double counting resulting from many cascading uses, i.e. using residues and recycled and recovered resources (e.g. Indufor 2013). Nevertheless, an approximate estimate for the implications for the by-product availability and for the bioenergy potential is created. We assume that the bioenergy production from sawmilling residues corresponds to around 50 percent of total sawnwood production, while the availability of sawmilling residues for cascading uses corresponds to the amount of sawnwood produced.[22]

The combined implications of the production trends and consumption scenarios (the apparent market imbalance) cannot be meaningfully calculated without considering net trade effects. Therefore, the implications of the production trends and consumption scenarios are given separately, i.e. by simply assuming that the European production could meet the demand in each scenario, without need for imports. Table 3.13 summarises the implications of the trend and scenario analysis. For comparison, the sawnwood production in the EU was around 98 Mm^3 in 2012, which would translate into bioenergy production of around 50 Mm^3 and by-product availability of around 100 Mm^3, if assuming the same multipliers as for the scenarios.

The production trend for the period 1992-2012 would imply a 50 percent increase in the residue availability from the 2012 level by 2050. Instead, the trend for the period of 2000–2012 (Trend 2) would show no changes to the situation in 2012 towards 2050.

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[22] According to Keränen and Alakangas (2013), the production of 100 m^3 of sawn timber creates 37 m^3 solid biofuels. Added to that are the chips left over from sawmilling which are used for secondary processing. The amount of by-products is slightly more than the amount of finished sawnwood products (112 m^3). From that amount of residues, around 17 m^3 would be directed to energy use as by-products from mechanical pulping and wood-based panel production. Chemical pulping would produce another 50 m^3 of black liquor, but the raw material does not come (only) from sawmilling by-products, so that it is ignored in this context. Therefore, we simply assume that each unit of sawnwood produced leads to around 1/3 of that amount for direct bioenergy production, and a 1/6 of that amount to bioenergy production through the cascading uses of the by-products, i.e. around 50 percent of total sawnwood production in total (and 25 percent of total wood use in sawnwood production). The availability of by-products for cascading uses approximately corresponds to the amount of sawnwood produced, since the wood use coefficient for sawnwood production is around 2.1.

Scenario 4 suggests a massive increase for the wood chip availability compared to the level of 2012, i.e. a 180 Mm^3 increase in the by-product flow and a 90 Mm^3 increase in the bioenergy production from sawmilling residues. In contrast, scenarios 1 and 3 suggest no change to the level of 2012, while the scenario 2 suggests a 75 percent decline compared to the level of 2012.

Table 3.13 Implications of the Trend and Scenario Analysis for the Cascading Uses and Bioenergy Potential.

	2012	2030	2050
Reference			
By-product availability (Mm^3 RWE) - estimate	100		
Bioenergy production (Mm^3 RWE) - estimate	50		
Production - trend projections			
By-product availability (Mm^3 RWE)			
Trend 1		135	167
Trend 2		105	101
Bioenergy production (Mm^3 RWE)			
Trend 1		68	84
Trend 2		52	50
Consumption - scenarios			
By-product availability (Mm^3 RWE)			
Scenario 1		105	110
Scenario 2		60	27
Scenario 3		93	93
Scenario 4		187	278
Bioenergy production (Mm^3 RWE)			
Scenario 1		53	55
Scenario 2		30	13
Scenario 3		47	46
Scenario 4		93	139

In short, it would be more beneficial from the point of view of raw material availability for cascading uses and bioenergy production, if the sawnwood production and consumption would continue the trend of the period 1992–2012 (Trend 1), compared to the trend for the period of 2000–2012 (Trend 2). The largest effect would be caused by Scenario 4, where it is assumed that the sawnwood consumption per capita would triple by 2050 and the production is able to meet the demand. *In this rather extreme case, the bioenergy production from sawmilling residues in the EU27 would increase by around 90 Mm^3 from the level of 2012 (50 Mm^3) by 2050.*

However, the figures are subject to many simplifying assumptions and explicit contradictions, so that differing views can certainly be raised. Some sources argue that the competing uses of the sawmilling by-products consume most of the potential already (e.g. Saal 2010), and the future potential for bioenergy from sawmilling residues therefore depends on the market developments especially in the pulp, paper, and wood-based panel industries. Also, the importance of the sawmilling residues in terms of bioenergy production varies greatly from one region to another. For example, in Finland the primary source of forest bioenergy is small wood (and black liquor) rather than residues from the wood products industry. Consequently, it may be that considering the indirect multiplier impacts of sawlog harvesting on the small tree harvesting would be even more important than calculating the sawmill by-product flows. However, the incentives and expectations of the forest owners are very difficult to quantify for this context. Also, producing simple trend projections for decades ahead may be a questionable premise for deriving implications for the bioenergy potential, as it is possible that the current industry structures are already vanished by 2050.

3.2.7 Summary - Critical Factors Affecting the Sawnwood Markets

The construction sector in Europe and North America is experiencing an exceptionally severe recession, which has also been mirrored to the sawnwood markets. However, in Europe the recovery is seen to take much longer compared to North-America, due to for example overbuilding prior to the crisis, chronic regional unemployment, consumer sentiment remaining low, and modest economic growth in the EU (Taylor et al. 2013). The capacity utilisation rate will recover towards the pre-crisis levels once the construction activity returns to the long-term averages, but it remains to be seen whether the lost capacity will be added back to the markets, or if there will be structural consequences. According to Taylor et al. (2013), the total capacity in Europe has not decreased despite many capacity closures, partly due to municipalities being willing to refinance the sawmill industry that provides employment and partly because of the fragmented structure and the relatively low capital intensiveness of the industry. However, the overcapacity problems have led to low or negative profitability, and without very significant restructuring of the industry, it is unlikely to improve significantly.

The synthesised outlook studies and also the trend projections suggest that the slowly growing or even declining sawnwood production and the more vigorously growing wood-based panel production would imply increasing competition on the sawmilling residues, which is likely to induce upward pressure on the price of forest biomass. However, the gap between earlier assessments on the European sawnwood consumption and the trend projections based on the latest available data corresponds to tens of millions of cubic meters by 2030. It follows that the long-term trend projections for the global sawnwood markets need to be updated.

Even though the period of low economic activity is expected to come to an end at some point in Europe as well, the historical trends and the main demographic and economic indicators of demand in Europe do not seem to support strong growth for sawnwood demand in the long-run. Realising the high growth prospects would require changes in the consumption per capita, i.e. changes in the market share of sawnwood in the construction markets. For example, prefabricated wooden multi-storey element systems could substitute concrete element systems. This kind of a development would probably translate into higher value added for the industry and less wood use, implying reduced availability of sawdust and chips, but better theoretical raw wood availability (apart from logging residues).

Most of the sawmilling by-products (woodchips and sawdust) are currently used for wood-based panel production and pulping. Based on the trend and scenario analysis, massive direct effects of sawnwood consumption patterns on the bioenergy production potential appear unlikely, although possible. However, the indirect effects related to wood mobilisation from the forest are very important, yet difficult to quantify.

The critical factors affecting the volume of sawnwood production and thereby the bioenergy potential could be argued to include the following points.

1. The demographic and economic development in Europe and the export markets:
   - How much time will the recovery from the financial crisis take in Europe?
   - Will the recession affect the industry structure (capacity vs. utilisation rate)?
2. Structural changes (substitution) in the construction markets:
   - There are large regional differences in the consumption per capita of sawnwood across Europe: Are there opportunities for increased wood-frame construction, either in the traditional low-rise construction, or e.g. in non-residential and multi-storey sectors?
   - Will the emphasis in future be more towards industrial practices with smaller volumes, and the high-end of the value chain (the role of a builder), rather than staying as a producer of basic products?
3. Competitiveness of sawnwood producers:

- ➢ What will be the level of investments in Eastern Europe, Russia, and the rising giants (China, India, where also a huge bioenergy potential in by-products)?
- ➢ Is the potential for integrated bioenergy production in the forest industries significant enough to boost sawnwood production (significant effect on profitability)?

3.4 Forest Biorefinery Development

3.4.1 Background and Motivation

The bio-based economy is expected to grow significantly in coming next decades, and biorefining will be one of the pillars of this development. Forest biorefineries play a role in this transition, particularly in the countries with high-quality research and development, mature state in the forest-based industries, and abundant lignocellulosic biomass resources.

A forest biorefinery can be understood as a multi-product factory that integrates biomass conversion processes and equipment in order to produce bioenergy and bioproducts from wood-based (lignocellulosic) biomass (e.g. NREL 2012). An important goal of a forest biorefinery is to more efficiently utilise the entire potential of raw materials and by-streams of the forest-based sector for a broad range of products (Mensink et al. 2007). However, there are no nation- or industry-wide solutions for how a forest biorefinery should be developed and implemented. In the literature, three different generations of biorefineries have been identified. In general, first generation biorefineries are based on direct utilisation of classical forms of agricultural biomass (conversion of sugar-rich biomass by fermentation to bio-ethanol or conversion of oil-rich biomass by transesterification to bio-diesel). Second generation biorefineries are defined as facilities that utilise lignocellulosic biomass as a raw material, one of the biggest advantages being that this reduces dependence on food crops required for first generation biorefineries. Third generation biorefineries have the advantage of utilising agricultural, forestry, petrochemical, and urban wastes (e.g. CRIP 2012, Naik et al. 2010). The conversion technologies can be classified into three different pathways: bio-chemical, thermo-chemical, and physical-chemical. In addition, the different processes can be to some extent combined. Some of the conversion technologies are already mature and commercial, whereas others require development to move to commercial applications. Overall, within the forest biorefinery context, there are a number of different product and technological possibilities.

As biorefining business continues to take shape, it is important to have understanding of potential, different options, and drivers related to biorefineries. Although challenges related to biorefineries should neither be seen as purely technical problems nor as issues

unconnected to society, the studies related to forest biorefineries have largely been technologically focused until recent years (e.g. Wising and Stuart 2006, Söderholm and Lundmark 2009). Many studies have discussed about developing processes and technologies for the conversion of biomass into various types of bio-products (e.g. van Heiningen 2006, Saxena et al. 2009). However, it seems that during the last few years the perceptions of academics, politicians and the involved industries themselves have widened from an exploration of biorefineries from a purely technical perspective to more holistic approaches, and issues such as socio-economic and political aspects, sustainability, company strategies and evaluation of whole value chain have been taken into consideration. (e.g. Söderholm and Lundmark 2009, Kangas et al. 2011, Mateos-Espejel et al. 2011, Melin and Hurme 2011, Pätäri et al. 2011, Turriff 2011, Kretschmer, et al. 2013). In this chapter the aim is to give an overview about the potential forest biorefinery concepts, current state and future prospects of biorefinery business development. This synthesis aims also to describe the key drivers and challenges for the biorefineries as well as implications to other forest products markets. Most importantly, the objective here is to summarize the critical questions that should be taken into account by the companies that are transforming their business models towards biorefining business.

The findings of this chapter are based on a literature review on forest-based sector outlook studies, biorefinery-related studies and research papers. The emphasis is given to the developments in Europe and North America.

3.4.2 Biorefinery Concepts

3.4.2.1 Routes, Raw Materials and Products

Many studies and reports indicate that forest biorefineries cannot be limited to one raw material, process or product. Instead, the case-specific circumstances, such as raw material availability and prices, energy prices, regulatory conditions and the specific features of the facility with which biorefinery can be integrated will define the biorefinery model that is ultimately chosen. (e.g. Chambost et. al. 2008, Unece/FAO 2011, Star-Colibri 2011, IEA 2012, Brown and Brown 2013, Moshkelani 2013).

Conversion technologies vary notably both in terms of feedstock preference and in terms of the end products they produce. Prominent distinguishing factors of the different technologies are their cost, their complexity as well as their development status. The choice of conversion technology has impact on the quality of the final products derived, which in turn influences on their marketing potential and cost. (Kretschmer et al. 2013) Following the IEA World Energy Outlook, EUwood study assumes that the biochemical conversion and the production of cellulosic ethanol from wood fibres will represent 80 percent of liquid biofuels production in future, whereas the thermo-chemical (biomass to liquid - Btl) conversion will only represent 20 percent of future liquid biofuels production (Mantau et al. 2010a). For example, Brown and Brown (2013) evaluated that in the U.S.

cellulosic ethanol via enzymatic hydrolysis will represent the largest pathway in 2014 by volume (28 percent of total). However, they also indicated that one possible benefit for the future commercialisation of cellulosic biofuel pathways is the notably larger capacity of the thermo-chemical facilities relative to the biochemical facilities (Brown and Brown 2013).

In the recent three-phase Delphi study on forest biorefinery diffusion in Scandinavia and North America (conducted in 2008–2011), the most potential forest biorefinery concept for the studied countries was defined by the representatives of forest, bioenergy and bioproducts sectors (Näyhä 2012). As a basic future biorefinery concept, respondents of the study indicated facilities with 100,000–200,000 to 300,000 or even 500,000 tons per year of biofuel production capacity. Fischer-Tropsch diesel was assumed to be a principal product. Forest residues (logging tops, pre-commercial thinnings and stumps) and mill residues were considered to be the most significant wood-based biomass sources in future biofuel production (see also e.g. Browne 2011). There were also country-specific biomass sources that were believed to have potential: peat in Finland, black liquor in Sweden and disease-killed timber in Canada. Experts in the study also highlighted the evaluation of feasibility and the potential of various feedstocks in addition to forest residues, and urban organic waste in particular was believed to have future potential. In addition to high-volume bulk products the significance of various low-volume, high-value bio-products, such as synthetic polymers, viscose fibre derivatives, nanotechnology products, intelligent paper and packaging, and composite materials, were seen as crucial for economic competitiveness. Value-based business models instead of volume-based business models were highlighted particularly during the last research phase of the study. Likewise, flexibility in raw material and end products, (meaning that the portfolio could be adjusted according to prevailing market situation) was increasingly emphasised during the last research round.

Companies have difficulties to identify the most promising biorefinery product portfolio with the most interesting economic potential because many framework conditions must be considered (IEA 2013a). Modeling and optimisation is necessary, for example, when evaluating the trade-off between the amount of transportation biofuel produced versus deriving economic benefits from the co-products. Also, the optimal product portfolio can change over time as the product markets can change, policies evolve, and new technologies will be developed (IEA 2013a). Näyhä and Pesonen (2013) found that the most prominent factor when selecting a product portfolio in forest biorefineries is the market price of the end product. Chambost et al. (2008) highlight in their study that product portfolio changes should be carefully designed as a driver of company profits, but must also be able to meet other goals, such as addressing customer expectations relative to existing and new products. It also appears that, before the most optimal biorefinery models

and products are found, there will be plenty of fluctuation and many start-ups that will not be successful in the long term (Näyhä and Pesonen 2013).

Many studies increasingly highlight the importance of diverse raw material sources and the production of high-value, low-volume co-products in addition to comparably low-value biofuels. (e.g. Cohen et al. 2009, IEA 2011, Näyhä 2012) In general, considerable potential is seen in advanced, third generation biofuels and innovative bio-based pathways that are based on wastes and residues (e.g. IEA 2013c, Kretschmer et al. 2013). Seeing biorefineries even as more versatile facilities with a diversified product portfolio is understandable as biorefinery development progresses: increasing knowledge with rising availability of the results and experiences from research and demonstration projects provide the basis for wider understanding.

3.4.2.2 Integration and Location

There has been plenty of interest in biorefineries integrated into the pulp and paper industry, especially in the traditionally big forest industry countries in North America and Western Europe, where the forest-based sector companies are seeking to re-innovate their strategies, products and business models (e.g. van Heiningen 2006, Toland 2007) Many documents suggest that incorporating a biorefinery unit within an operating pulp and paper mill has prominent technological, economic and social advantages over the construction of a grass root biorefinery (e.g. Thorp 2005, van Heiningen 2006, Näyhä 2012, Star-Colibri 2011, Moshkelani et al. 2013). In fact, this is already happening as the pulp and paper industry is steering its strategies more towards energy and biorefining businesses.

The location of biorefinery facilities and the transporting of biomass will be one of the key issues when planning and implementing forest biorefinery facilities. It appears that logistics of cellulosic feedstock that has low bulk density is a prominent technical and economical challenge for cellulosic biorefineries (e.g. Hess et al. 2007, Stephen et al. 2013, Kretschmer et al. 2013). Additional negative effects of raw material exporting could include reducing the national employment rate, stunting growth of national products and adversely affecting the security of the energy supply. On the other hand, another major factor will be labour costs, and it is possible that it is economically feasible to export biomass for processing to countries where labour costs are lower. Here, one of the key questions is if the biorefineries will eventually be located in areas with plenty of affordable biomass and low labour costs, even if the first pilot and demonstration facilities are built in Scandinavia and North America. It also needs to be taken into an account that according to many estimations forest biorefineries are not economically attractive without the integration with pulp and paper mills, and thus, success of biorefineries is dependent on future prosperity and location of pulp and paper mills. Therefore, identification of national strengths and the roles of companies in the biorefinery value chains are crucial in order to succeed in the

long term. For example, Asikainen et al. (2012) state that although local biofuel production has some cost benefits in domestic markets, it is still unclear how much resource should be invested in large-scale, export-oriented biofuel production in Finland.

Overall, it appears that in future there will be a range of biorefineries in different size scales utilising several types of biomass feedstock and various technology options. Different technologies, e.g. thermo-chemical, physical-chemical and biochemical conversion processes, will be used to provide optimal process concepts for each feedstock and product. (e.g. Mäkinen et al. 2011, Koljonen and Similä 2012, Brown and Brown 2013).

3.4.3 Transport Biofuel Production and Biorefinery Facilities: from Visions to Operating Facilities

It seems that the hype and overly optimistic estimations that was related to renewables in general, and to the biorefinery business has passed, and at all the levels of the business environment more realistic plans and approaches are being made today. The biorefinery industry is at the critical stage of making the shift from pilot demonstration to successful commercial activity (Kretschmer et al. 2013).

3.4.3.1 Biofuel Production and Consumption: Goals and Visions

The goal of the European Biorefinery Vision 2030 is that 25 percent of Europe's transport energy needs are supplied by biofuels, with advanced fuels taking an increasing share, and that 30 percent of overall chemicals productions is bio-based (Star-Colibri 2011). All the Nordic countries in EU must comply with the EU target of 10 percent renewable energy in the transport sector by 2020. Finland and Sweden aim to surpass the minimum 10 percent EU target. Finland has set the biofuel distribution obligation as high as 20 percent in 2020 (Heinimö and Alakangas 2011). In Finland, around 30 percent of renewables in the transport sector are expected to be produced from second generation biofuels (IEA 2013b).

According to World Energy Outlook Study (IEA 2013c) global consumption of biofuels increases from 1.3 M barrels of oil equivalent per day (mboe/d) in 2011 to 4.1 mboe/d in 2035, to meet 8 percent of road-transport fuel demand in 2035. It is believed that advanced biofuels gain market share after 2020, reaching 20 percent of biofuels supply in 2035. Ethanol remains the dominant biofuel, making up almost 80 percent of global biofuels use throughout the period. The USA, Brazil, the EU, China and India account for about 90 percent of world biofuels demand throughout the studied period, with government policies driving the expansion in these regions. The U.S. remains the largest biofuels market, whereas Brazil will be the second-largest market and continues to have a larger

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share of biofuels in its transport fuel consumption than any other country. Biofuels use in the EU more than triples over the period, representing 15 percent of road-transport energy consumption in 2035 (IEA 2013c).

According to recent IEA report (IEA 2013b) biofuels will play a significant role in the future transport sector in all the Nordic countries. The share of biofuels of total fuels used for transport by 2050 varies from some 25 to 70 percent in different scenarios. The study indicates that in addition to biodiesel production from wood raw materials, there is also a remarkable bio-ethanol production. About 60 percent of Nordic biofuel demand in transportation is covered by domestic sources in all the presented scenarios.

In VTT's low-carbon scenarios (Koljonen and Similä 2012), the demand for transport biofuels in Finland would account for up to about 40 percent of the total final energy in the transport sector by 2050. Domestic production in Finland is not projected to be able to meet such a high demand, and a large part of it would have to be met by imports. The results indicate that a domestic production of 30–35 PJ (petajoule) could be achieved by 2050, accounting for 50–65 percent of the demand in Finland (Koljonen and Similä 2012).

3.4.3.2 Biorefinery Facilities

While a few commercial-scale units and about 100 plants at pilot or demonstration scale already exist, widespread business deployment of biorefinery facilities have not taken place by so far (IEA 2013d). Nevertheless, several commercial plants are close to operationalisation, both in Europe and rest of the world. Fortum's bio-oil facility (production capacity of 50 000/y), which uses fast pyrolysis technology and forest-based biomass, got started very recently in Joensuu, Finland. Like Joensuu facility, other biorefinery plants that are close to operationalisation, are all based on the use of wastes and residues (Kretschmer et al. 2013) It is particularly noticeable that the vast majority of current and planned plants at the pilot, demonstration and commercial scale, both in the EU and worldwide are for the production of lignocellulosic bioethanol. (Kretschmer et al. 2013).

Because of the lack of commercial scale production of advanced biofuels, the supply mandate for cellulosic biofuels under the RFS in the United States was reduced again in 2013 (IEA 2013c). However, nine biorefinery facilities with a capacity of 25 MGY or greater are expected to commence operations in 2013 and 2014. Thus, total US cellulosic biofuel capacity in 2014 will be 266 MGY on a volumetric basis (215 million gallons on a gasoline-equivalent basis). While this capacity will place the cellulosic biofuel mandate of the RFS2 more than three years behind schedule (the unrevised mandate required 250 MGY of production in 2011), the production of commercial-scale volumes of cellulosic biofuel will represent a significant breakthrough for the cellulosic biofuels industry. These facilities will employ six different pathways; three pathways producing hydrocarbon-based biofuels and three producing cellulosic ethanol. Cellulosic ethanol via enzymatic hydrolysis will represent the largest pathway in 2014 by volume (28 percent of total). The role of these

facilities is considered important in determining the future composition of the industry, because they will provide data regarding the technical and economic feasibility of various cellulosic biofuel pathways on a commercial scale. (Brown and Brown 2013).

Several countries in Europe, particularly in Western Europe, are active in the commercialisation of advanced biofuels both from thermo-chemical and biochemical conversion. As of October 2013, there were 30 biorefinery facilities in operation or under construction. Majority of these were pilot or demonstration facilities using lignocellulosic biomass as raw material. Eight of those utilise thermo-chemical conversion route and 18 biochemical conversion technologies. (IEA 2013e).

In Finland, the VTT's detailed baseline scenario contains an assumption that there will be 2–6 new biodiesel production facilities in Finland by 2030, with combined production capacity of 500 000 tonnes. According to this scenario there will be also four bio-oil production plants (2–3 facilities producing 140 000 tonnes/years bio-oil by 2020 and 2–3 facilities producing 180 000 tonnes/year by 2030). In addition of these there will be one syngas production facility (1.5 TWh/year) that feeds syngas into natural gas grid by 2020. According to this study Finland would be a net exporter of biofuels by 2030 (Pursiheimo et al. 2013). Compared to this detailed basic scenario, the experts in the recent Delphi study on biorefinery diffusion were less optimistic: Although many respondents expected to see several biorefinery projects started in a three- to-five-year time frame, it was believed that in ten years' time (by 2020) there will be only three large-scale biorefinery facilities operating in Finland (Näyhä 2012). In addition of Fortum facility in Joensuu, the step towards fulfilling the scenarios in the form of commercial scale biorefinery is UPM facility in Lappeenranta, which is currently under construction. The biorefinery will produce annually approximately 100 000 tonnes of advanced second generation biodiesel from crude tall oil for transport. There are also several other initiatives ongoing in Finland (e.g. Green Fuel Nordic, ST1).

3.4.4 Key Drivers and Challenges for the Forest Biorefinery Development

3.4.4.1 Macro-Scale Factors

It appears that incentives that promote the biorefinery business must stem from several sources. There needs to be encouraging signals from the macro-scale environment: the high price of oil, national security of the fuel supply, availability of public and private financing, demand for bioenergy and bioproducts as well as long-term and predicable energy and environmental policies (e.g. IEA 2009, IEA 2013b, Näyhä 2012, Kretschmer et al. 2013). For example, the global recession and related drop in oil price in 2008-2009 were seen as temporary negative factors for the development of biorefineries and lignocellulosic biofuels (Näyhä and Pesonen 2012).

More support for the investments for the first demonstration and pilot plants are needed to bring these developments to full-scale operations (IEA 2011, Näyhä 2012, Pursinheimo et al. 2013, Kretschmer et al. 2013). The European bio-based sector is active in investing in piloting and demonstration, but the large investments in commercial-scale plants are concentrated in Asia and North and South America (WEF 2010, Carus 2012). Particularly governments are expected to accelerate development through public RD&D and to reduce risks associated with large investments when technologies are immature (IEA 2013b). The outlook for biofuels is strongly dependent on changes in government subsidies and blending mandates, which appears to remain the main incentive for biofuels use (IEA 2013c). However, it has also been suggested that while governmental incentives can quicken and encourage start-ups, businesses develop without governmental intervention in a more economically sustainable manner (Näyhä 2012). In addition, one potential threat to the development of bio-based product routes is the unbalanced encouragement of some production pathways at the expense of others (Carus et al. 2011, CEPI 2011).

The European Union has defined its renewable policy until 2020, but it is not clear how the policy will develop after that. To decrease the risk of investing in the first biorefineries long-term energy and climate policies that would also ensure the demand for biofuels in future, are needed (IEA 2013b, Kretschmer et al. 2013). Also national level coordination and strategies are needed to promote emerging biorefineries (e.g. Mäkinen et al. 2011, Star-Colibri 2011, Browne 2012, Näyhä, 2012).

3.4.4.2 Raw Material

The estimates of woody biomass potential stem from variety of assumptions regarding the economic, technical and environmental constraints that limit what could be mobilised in an otherwise unrestricted circumstances (Kretschmer et al. 2013). The high price of raw material is one of the biggest threats to new biorefinery business, particularly from the perspective of the involved industries (Thorp and Akhtar 2009, Näyhä 2012). Many studies indicate that along with the increasing demand there will be more pressure on prices. On the other hand, reduced pulp and paper production will decrease competition for forest-based biomass (as described in the previous chapters), thus improving possibilities for other forms of biomass utilization, such as forest biorefineries. Overall, it is obvious that successful implementation of the biorefinery business is dependent on raw material availability and price, and requires the efficient exploitation of existing wood biomass resources. (e.g. Cohen et al. 2009, Näyhä 2012).

Also the evaluation of the potential of various feedstocks in addition to forest based biomass will be important (Cohen et al. 2009, Rättö 2009, Mäkinen et al. 2011, Star-Colibri 2011, Näyhä 2012) and many documents indicate that the range of raw materials processed by future biorefineries (even if operated by the forest-based industries) will be broadened to include agro-materials and various recycled materials ("urban biorefinery")

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(FTP 2013). Flexible technologies that could process variety of feedstocks are thus expected to be important (e.g. Cohen et al. 2009). Many documents also present scenarios about circular use/economy of wood (also concept of "cascading" is brought up in this context), meaning recycling wooden materials through various processes and purposes before finally generating energy (e.g. Mantau 2012, IEA 2013a, Näyhä and Pesonen 2013, Kretschmer et al. 2013).

3.4.4.3 Sustainability

There are both prominent opportunities and threats related to the wood raw material used in the biorefinery business. Often use of wood is considered environmentally sustainable, given its intrinsic status as a renewable natural resource, and in general, environmental sustainability is an important driver for the forest biorefinery business. Accordingly, having an environmentally sustainable image can also be a competitive advantage for companies. (e.g. Näyhä and Horn 2012). However, in addition to price challenges related to raw material, using wood as raw material is also seen as a threat from the environmental perspective, and the environmental challenges related to forest biorefinery activities are widely recognised by many studies (e.g. Buchholz et al. 2009, Soimakallio et al. 2009a, Uihlein and Schebek 2009, Mäkinen et al. 2011, Kretschmer et al. 2013). According to Näyhä and Horn (2012) from the perspective of environmental sustainability, harvesting feedstock will be the most challenging part of the biorefinery value chain to manage. One significant sustainability consideration relates to the impact of residue removal on soils and in particular soil carbon stocks, given that bio-based fuels and products are commonly indicated as a way to mitigate GHG emissions. Thus, it is important to note that bio-based products of any form should not be considered automatically sustainable per se (Buchholz et al. 2009, Näyhä and Horn 2012, Kretschmer et al. 2013).

At the same time, discussion of an environmental assessment of bioenergy and bioproducts clearly indicates that there is a lack of systematic approaches to assessing the environmental impacts of forest biorefineries (e.g. Soimakallio et al. 2009a, Uihlein and Schebek 2009, IEA 2013b). Currently, criteria that do not consider sector-specific features and variation (such as location, raw material, end products) are used. However, using non-specific criteria in assessments can create many problems, e.g. the most relevant concerns do not emerge in evaluations. It is indicated that even though bio-based systems have been approached mainly from the life-cycle perspective (e.g. Soimakallio et al. 2009b, Uihlein and Schebek 2009, van Vliet et al. 2009, Cherubini and Stromman 2011, Gonzalez-Garcia et al. 2011), this alone is not a comprehensive approach for forest biorefinery evaluation (Cherubini and Stromman 2011) rather, a more particular approach would be applicable. In their recent study Näyhä and Horn (2012) found out that raw material availability and its sustainability were the most important criteria in the environmental sustainability assessment of forest biorefinery value chain companies. It is also important to realise that the use of wastes and residues is not sustainable per se. For

many of the commonly proposed residue sources there is a range of existing uses, which will be displaced. This means that potential indirect effects must be taken into an account. (Kretschmer et al. 2013).

Introducing appropriate sustainability criteria should be seen as a long-term benefit rather than a barrier or retard to the development of the biorefinery sector. Overall, increased public awareness could facilitate use of biomass and biorefining business in general, whereas uncertainty about the sustainability of bio-based products may create a barrier to the biorefining sector's development, particularly in light of the on-going discussion on conventional biofuels and challenges related to those (Kretschmer et al. 2013).

3.4.4.4 Collaboration and Partners in Biorefinery Consortia

There is need for collaboration between all value chain actors in the biorefinery value chain. There is plenty of biorefinery research in Europe, but it is often fragmented, and there are only few commitments to combine resources and knowledge (Elvnert 2012). Thus, the research community and industry should aim at establishing a consensus how to proceed with different biorefinery possibilities, and public and private partnerships should be formed in order to bring technologies to full scale operation (IEA 2011, Elvnert 2012). Collaboration between industry, the knowledge infrastructure (institutes and universities), government, and NGOs to identify appropriate R&D priorities as well as commercialisation strategies are required (IEA 2009, Näyhä 2012). There is also a need for international networking, and from the perspective of Finland, establishing stronger collaboration between Nordic countries (Mäkinen et al. 2011, Näyhä 2012, IEA 2013b).

Chambost et al. (2008) suggest that biorefinery partners should be identified early on in the biorefinery development phase. It also appears that value creation through collaboration has become increasingly important as a means of filling the resource gap in the energy and forest sectors in the bioenergy business (Pätäri 2009). Firms can obtain knowledge through patents and other immaterial rights or they can acquire companies with the relevant competitive knowledge and technologies. These companies can also come from outside the traditional forest sector (Pätäri 2009, Eloranta 2010, Hetemäki et al. 2011). Forest biorefinery consortia also offer small companies a possibility to enter new, larger markets, and small companies should be encouraged to be more active in RD&D (particularly in developing new high value-added products) and collaborate with larger companies (Mäkinen et al. 2011, Näyhä and Pesonen 2012). Näyhä (2012) found in her study that the forest industry was considered the most potential dominant actor in a forest biorefinery consortium following the importance of the petrochemical and energy industries in the first Delphi round in 2008. However, in the last phase of the study (in 2011) the dominance of the petrochemical and energy industries was highlighted, whereas the forest industry's role was seen rather as a biomass provider, which manages raw material harvesting and logistics.

Overall, it appears that success in the forest biorefinery business will be based on partnerships through which the right set of skills can be achieved. However, collaborative management in the consortia brings also challenges, for example sharing profits and responsibilities between partners can be challenging (e.g. Janssen et al. 2008, Näyhä and Pesonen 2013).

3.4.4.5 Change Management and Required New Skills

Transitioning to the forest biorefinery business and changing the direction of an organisation in general present great challenges for leadership and management in involved industries. Operating a commercial-scale forest biorefinery facility requires both new managerial and operational-level skills. Establishing biorefinery business requires understanding of new markets and management of change as well as the development and implementation of economic and reliable technologies with related innovations and process expertise. (Thorp 2005, Näyhä and Pesonen 2013).

Näyhä and Pesonen (2013) explored strategic change in the forest sector towards biorefinery business, and according to their study both the need for change and key drivers for change are widely recognised within the forest industry, but actions and pathways largely still need to be created. The study shows that the renewal of the forest industry is not possible without a readiness for change and a resilient attitude, which are embedded in the organisational culture and management (see, Casti et al. 2011). The study also indicated that the forest industry needs leaders and managers who have – and are able to encourage – vision and strategic knowledge, as well as innovativeness, an enthusiastic attitude, willingness to seize new opportunities and open dialogue with stakeholders (see, Hansen et al. 2010). At the same time, the previously mentioned issues were seen as the most needed capabilities in the companies.

Overall, it appears that many countries have potential for success in the forest biorefinery business. It also seems that countries interested in biorefinery business have many common issues that they consider in their particular strengths: technological knowledge, biomass availability, existing infrastructure and biomass logistics. Therefore, realistic identification of individual, unique strengths and continuous development of competencies would be crucial at the national level, as well as the ability to market the national know-how through international networks would be important in order to succeed in the global biorefinery business.

Like mentioned before, it is possible that the biorefineries will eventually be mainly located in areas with plenty of affordable biomass and low labor costs, even if the first facilities will be built in Scandinavia and North America. This further highlights the need of countries and organisations to carefully consider their roles in the biorefinery value chains and their long-term potential in the biorefinery business.

3.4.5 Implications to Other Forest Products and Bioenergy Markets

Increased demand for lignocellulosic biomass is one of the key questions that arises in the context of forest biorefineries. This in turn has effect on the other forms of forest utilisation, wood raw materials markets and the national economy (e.g. Kallio et al. 2011, Jonsson 2013, Kraxner et al. 2013).

Pursinheimo et al. (2013) state that investments on biorefineries have greater impacts compared to some other investments because biorefineries arouse higher demand for forestry, and therefore, has a greater impact on income of private households as well on national product. Biorefineries will also increase investments in the other sectors.

In addition, biorefineries also make a notable contribution by bringing opportunities for social and economic development particularly in rural communities by providing "green" jobs (CEPI 2011).

3.4.6 Conclusions and Summary of Critical Issues

Forest biorefineries are considered an environmentally and economically sustainable new business opportunity in many studies, and it appears that biorefineries will be part of the future bioeconomies in one way or another. It appears that the hype that was related to the biorefinery business has largely passed, and more realistic approaches and goals are currently planned.

Nevertheless, in addition to considerable opportunities, there are also many risks related to biorefinery implementation. Now, when many technologies are close to the stage of commercial applications, there is a need for a synthesis of current knowledge and estimations, as well as for analytical assessment of presented future prospects, potential and challenges. What are the critical questions that should be paid emphasis, first, by the society in general, and particularly by the companies that could transform their business models towards biorefining? Critical questions and challenges can be summarised as follows:

1. Visions and goals:
   - ➤ Challenge: Availability of reliable and practical information about biorefinery development, e.g. can current lignocellulosic biofuel production goals considered realistic?
2. Competitive advantages and focus at company, sector and national levels:
   - ➤ How to choose the most promising portfolios in biorefineries (Services/high value-added products/large-scale manufacturing)?
   - ➤ Challenge: Recognising long-term competitiveness and strengths.
3. Environmental and energy policies:

- ➢ Creating effective support and subsidies mechanisms for the first biorefinery facilities.
- ➢ Challenge: Uncertainty of policies.
4. Forest-based biomass availability and price development:
   - ➢ Recognising linkages with other forest-based industries (integration, by-products/waste streams/forest residues).
5. Sustainability:
   - ➢ How to find environmentally/socially sustainable business models to realise forest biorefineries?
   - ➢ Challenge: Lack of systematic approaches to assess environmental impacts of forest biorefineries.
6. Readiness for change and management of biorefinery consortia:
   - ➢ How to manage strategic change towards new biorefinery business (collaboration, capabilities and resources)?
   - ➢ Challenge: Sharing responsibilities and profits in consortia.
   - ➢ Challenge: Recognising the role of SMEs/companies outside the traditional forest sector/novel opportunities in the interfaces of different sectors.

4. Forest Bioenergy Outlook

4.1 Background

All the parts of a tree, i.e. woody biomass, can be used as a source of energy. The framework is simple: firstly, woody biomass, such as stemwood and branches, is collected, secondly biomass is refined into a biofuel, such as chips, and thirdly, the biofuel is converted, for example by combustion, into bioenergy, such as heat and electricity. However, when exploring the literature related to the use of wood, or generally biomass, in energy production, one encounters a myriad of terms, classifications, approaches, models, technologies, conversion factors, underlying restrictions, and assumptions, for example, which makes the comprehension, interpretation, and comparison of the widely varying results arising in different studies challenging.

The various concepts and their rather unestablished use hardly alleviates ones struggle through the multitude of studies, reports, outlooks, political declarations, and pamphlets pertaining wood based bioenergy. Moreover, uncertainties related to the data, chosen approaches, methodology, and the numerous assumptions are considerable, yet their effects on the results are not always critically evaluated. For example, the statistical sources available provide diverse figures on seemingly identical items. A part of this problem is related to unambiguous classifications, yet the major issue is that many forms of the use of wood as energy are not included in the official statistics due to such reasons, for example, that they are not traded in the markets, such as fuelwood used by households, or their use has started to grow just recently, such as forest chips. In the following, firstly, an attempt is made to provide an overview of biomass resource assessment and then proceed to forest bioenergy resources while discussing some of the most common concepts featured in literature and uncertainties related to the assessments in a critical yet accessible way. Secondly, selected major outlook studies of forest bioenergy are reviewed. The aim is to provide the reader some insight into the reasons affecting the differencing results and to assist the reader in identifying and evaluating the uncertainties related to procedures by which the results are obtained.

4.1.1 Resource Potential

Bioenergy production interacts with food, fodder and fibre production as well as with conventional forest products in complex ways. Bioenergy demand constitutes a benefit to conventional plant production in agriculture and forestry by offering new markets for biomass flows that earlier were considered to be waste products. It can also provide opportunities for cultivating new types of crops and integrating bioenergy production with food and forestry production to improve overall resource management. However, bioenergy production can intensify competition for land, water and other production factors, and can result in overexploitation and degradation of resources. For example, too-

intensive biomass extraction from the land can lead to soil degradation, and water diversion to energy plantations can impact downstream and regional ecological functions and economic services.

As a consequence, the magnitude of the biomass resource potential depends on the priority given to bioenergy products versus other products obtained from the land - notably food, fodder, fibre and conventional forest products such as sawn wood and paper - and on how much total biomass can be harvested in agriculture and forestry. This in turn depends on natural conditions on agronomic and forestry practices, and on how societies understand and prioritise nature conservation and soil/water/biodiversity protection and on how production systems are shaped to reflect these priorities.

4.1.2 Defining the Potentials

Studies quantifying biomass resource potential have assessed the resource base in a variety of ways. They differ on how the influence of present and future natural conditions is considered as well as in the extent to which the types and details of important additional factors, such as socioeconomic considerations, the character and development of agriculture and forestry, and factors connected to nature conservation, are taken into account (Berndes et al. 2003). Different types of resource potentials are assessed but the following are commonly referred to:

- **Theoretical potential** refers to the biomass supply as limited only by biophysical conditions.

- **Technical potential** considers the limitations of the biomass production practices assumed to be employed and also takes into account concurrent

    - demand for food, fodder, fibre, forest products,

    - area requirements for human infrastructure,

    - restrictions connected to nature conservation and

    - soil, water and biodiversity preservation.

- **Market potential** refers to the part of the technical potential that can be produced given a specified requirement for the level of economic profit in production. This depends on

    - cost of production and

    - price of the biomass feedstock, which is determined by a range of factors such as

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- characteristics of biomass conversion technologies,

- price of competing energy technologies and

- prevailing policy regime.

Most assessments of the biomass resource potentials are variants of methodology in which biomass resource potentials are quantified under the condition that global requirements for food and conventional forest products such as sawn wood and paper are met with priority.

The biomass categories in Table 4.1 are defined as follows:

- **Residues form agriculture.** By-products associated with food/fodder production and processing, both primary (e.g. cereal straw from harvesting) and secondary (e.g., rice husks from rice milling) residues.

- **Dedicated biomass production on surplus agricultural land.** Includes both conventional agriculture crops and dedicated bioenergy plants including oil crops, lignocellulosic grasses, short-rotation coppice, and tree plantations. Only land not required for food, fodder or other agricultural commodities production is assumed to be available for bioenergy. Large technical potential requires global development towards high-yielding agricultural production and low demand for grazing land. Zero technical potential reflects that studies report that food sector development can be such that no surplus agricultural land will be available.

- **Dedicated biomass production on marginal lands.** Refers to biomass production on deforested or otherwise degraded or marginal land that is judged unsuitable for conventional agriculture but suitable for some bioenergy schemes, e.g. via reforestation. There is no globally established definition of degraded/marginal land and not all studies make a distinction between such land and other land judged as suitable for bioenergy.

- **Forest biomass.** There are three classes of residues: (i) Forest sector by-products including both primary residues from silvicultural thinning and logging and secondary residues such as sawdust and bark from wood processing. Dead wood from natural disturbances, such as fires and insect outbreaks; (ii) Biomass growth in natural/semi-natural forests that is not required for industrial roundwood production to meet projected biomaterials demand, e.g. sawn wood, paper and board; and (iii) By-products provide up to about 20 EJ/a. Higher forest biomass technical potentials that correspond to a much larger forest biomass extraction for energy than what is presently achieved in industrial wood production. Zero technical potential indicates that studies report that demand from sectors other than the energy sector can

become larger than the estimated forest supply capacity. Literature studies range from zero to around 1,500 EJ (Smeets et al. 2007).

- **Dung.** Animal manure. Population development, diets and character of animal production systems are critical determinants.

- **Organic wastes.** Biomass associated with materials use, for example, organic waste from households and restaurants and discarded wood products including paper, construction and demolition wood. The actual availability depends on competing uses and implementation of collection systems.

Table 4.1 Global **Technical Potential** Overview for a Number of Categories of Land-Based Biomass Supply for Energy Production (primary energy numbers have been rounded).

Biomass category	2050 Technical potential [EJ/a]
Residues form agriculture	15–70
Dedicated biomass production on surplus agricultural land	0–700
Dedicated biomass production on marginal lands	0–110
Forest biomass	0–110
Dung	5–50
Organic wastes	5–50
Total	50–1000

The total assessed technical potential can be lower than the present biomass use of about 50 EJ/a in the case of high future food and fibre demand in combination with slow productivity development in land use, leading to strong declines in biomass availability for energetic purposes. Source: IPCC (2011).

Global biomass energy use currently amounts to approximately 50 EJ/a and all harvested biomass for food, fodder, fibre and forest products, when expressed in equivalent heat content, equals 219 EJ/a (2000 data, Krausmann et al. 2008). The potential range in the dedicated biomass production on surplus agricultural land has a huge uncertainty as it shows a range corresponding to the total global primary energy supply today.

4.1.3 Factors Affecting the Potential

To estimate biomass potentials, one has to integrate various dimensions of the question affecting to such potentials. One reason for the lack of integration is that the relationships between the issues are manifold and complex as can be seen in Figure 4.1.

It is not possible to narrow down the technical potentials of the biomass resource to precise numbers. A number of studies show that between less than 50 and several hundreds of EJs per year can be provided for energy in future, the latter strongly conditional on favourable developments. Land quality and availability form the main factors affecting the potential amount of biomass for energy production (Dornburg et al. 2010) so all the factors that affect the amount of land available for bioenergy production are in focus when considering the uncertainties of bioenergy potentials. To these include:

- Human dietary trends.

- Possibility to use degraded and marginal land areas for biomass production.

- Development in agriculture and forestry.

- Competition with other sectors for water resources.

Food demand and production depends on agricultural technology development and economic growth. All scenarios that predict global biomass potentials use food demand projections compiled by the FAO. The main assumptions consist of population growth and dietary trends. The largest uncertainties with regard to food demand are consumer preferences and the possibility to use alternative supply chains for protein: the change from animal to plant protein has a substantial impact on land use and water requirement. Such issues as achievable crop yields and feed conversion efficiencies in animal production are also among the main drivers of land use. Increasing yield in food production gives more possibilities for bioenergy.

Biodiversity is a word that is usually mentioned as a factor affecting bioenergy potentials. However, it is difficult to say what the word means in various studies. The practical consequence of taking biodiversity into account in estimating bioenergy potentials seems to be the exclusion of nature conservation areas from the land available for biomass production.
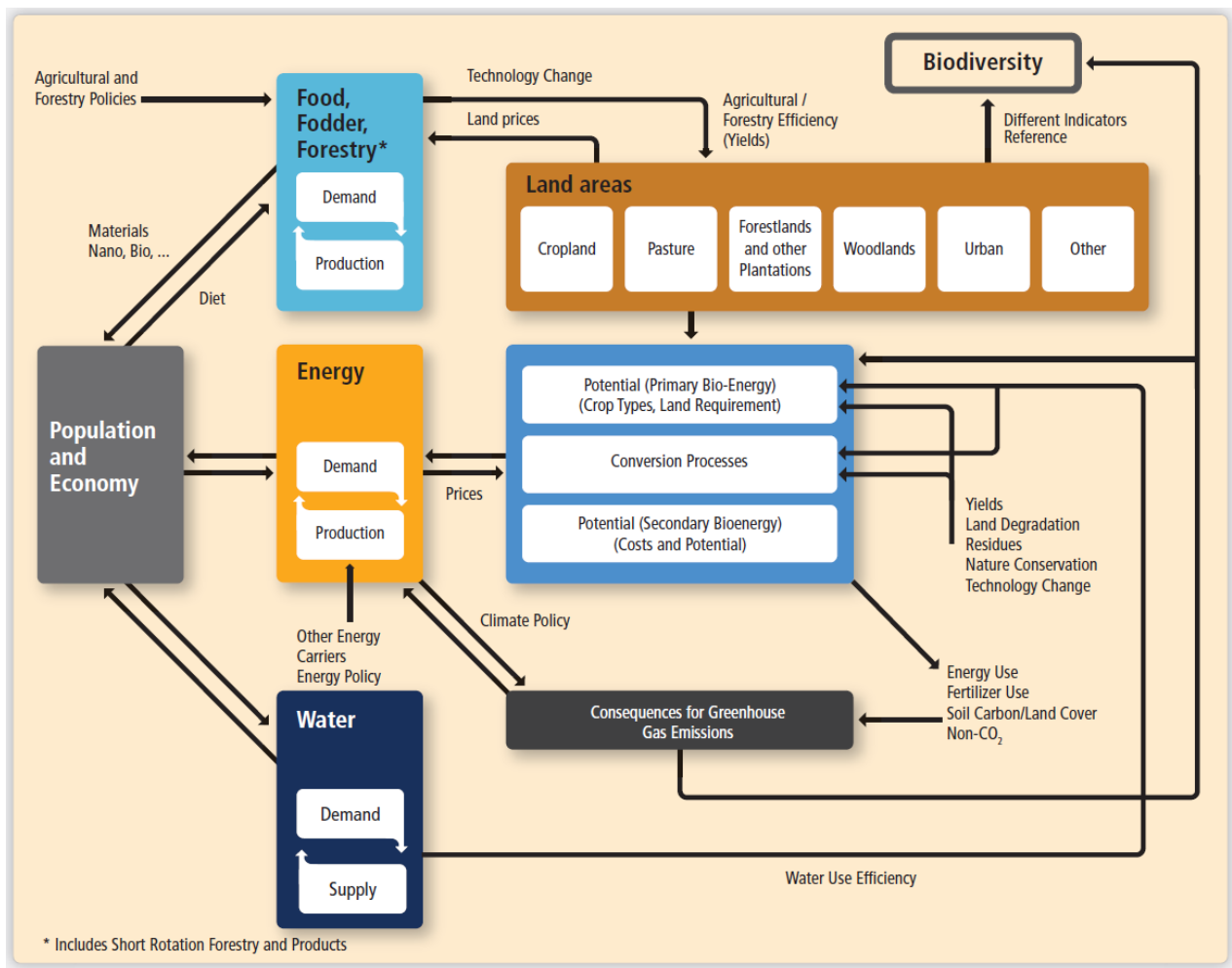
Figure 4.1 Overview of Key Relationships Relevant to Assessment of Biomass Resource Potentials. Source: IPCC (2011).

Water availability and use. The large variability in regional climate and hydrology necessitates detailed regional studies. Water availability has not been analysed on a sufficiently detailed spatial level to estimate regional biomass potentials in water scarce areas (Dornburg et al. 2010). The general trend is decreasing water availability in most regions, with the largest effects in those regions where water is already scarce. But in contrast to this trend, in high latitudes it is expected that the rainfall will increase. The other side of the water issue is its underline: Water use efficiency in agriculture can be improved which increases biomass potentials. The efficiency depends on many variables, such as crop choice, climate and agricultural practise.

Figure 4.2 shows the impact of technology development on land demand: the second generation biofuels for transportation are remarkably less land intensive. Change from conventional to advanced technology can be seen in land use.
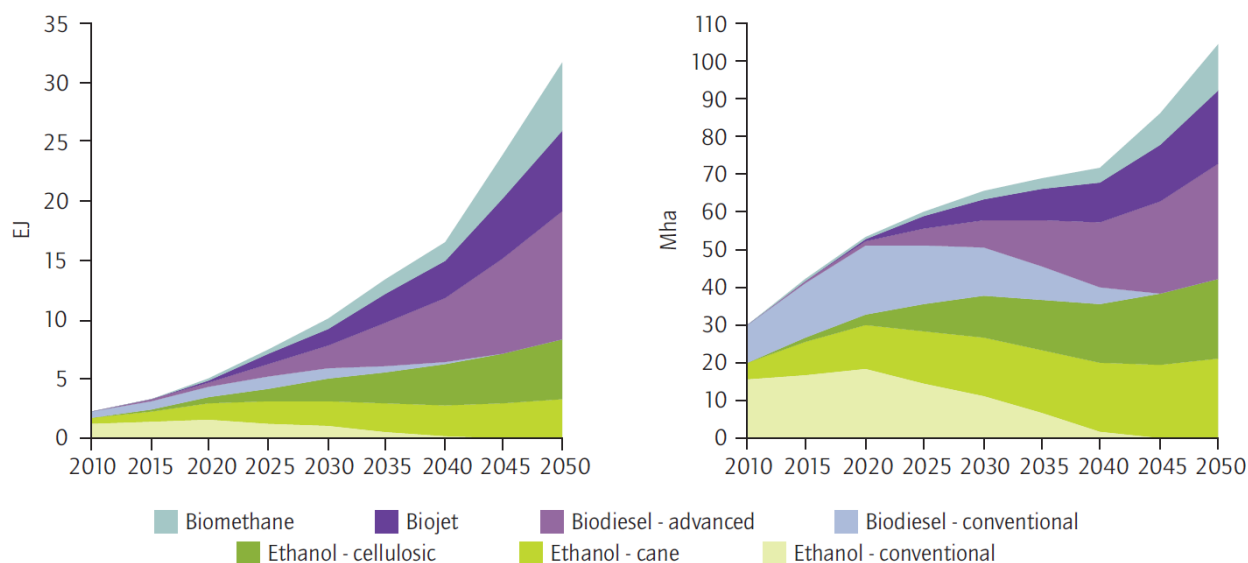
Figure 4.2 Demand for Biofuels (left) and Resulting Land Demand (right) (IEA 2011).

4.1.4 Potential Deployment

4.1.4.1 Current Deployment of Bioenergy

Modern (non-traditional) biomass use already provides a significant contribution of about 11 EJ out of the 2008 Total Primary Energy Supply (TPES) from biomass of 50 EJ. Traditional biomass use, between 60 and 70 percent of the total, is applied in rural areas and relates to charcoal, wood, agricultural residues and manure used for cooking, lighting and space heating, generally by the poorer part of the population in developing countries. From 1990 to 2008, the average annual growth rate of solid biomass use for bioenergy was 1.5 percent, while the average annual growth rate of modern liquid and gaseous biofuels use was 12 and 15 percent, respectively, during the same period (IEA, 2010c). As a result, biofuels' share of global road transport fuels was about 2 percent in 2008; and nearly 3 percent of global road transport fuels in 2009, as oil demand decreased for the first time since 1980 (IEA, 2010b).

Government policies in various countries fostered increase in global biofuels production during the last decade. Renewable wastes and biomass fuelled power generation represented 1 percent of the world's electricity generation in 2008 amounting to 259 TWh (0.93 EJ). Modern bioenergy heating applications, including space and hot water heating systems including district heating, accounted for 3.4 EJ.

International trade in biomass and biofuels has also become much more important over the recent years, reaching levels of up to 9 percent in 2008 of liquid biofuels traded

internationally and one-third of pellet production dedicated to energy use in 2009 (Junginger et al. 2010; Lamers et al. 2010; Sikkema et al. 2011). The latter has proven to be an important facilitating factor in both increased utilisation of biomass in regions where supplies are constrained and mobilising resources from areas where demand is lacking. The food versus fuel debate and growing concerns about other conflicts created a strong push for the development and implementation of sustainability criteria and frameworks and changes in temporisation of targets for bioenergy and biofuels.

4.1.4.2 Economic Considerations in Biomass Resource Assessments

The deployment of bioenergy is determined in the fuel markets and these are described in the energy system models used for assessing future energy scenarios. To describe the functioning of these markets and the role of bioenergy in them bioenergy supply curves are needed. Economists in wishing to avoid discussing many of the technical intricacies involved have chosen to construct an abstract model of production. In this model the relationship between inputs and outputs is formalised by a production function. The production function is assumed to provide, for any conceivable set of inputs, the solution to the problem of how best to combine those inputs to get output. For example, the production function might represent a farmer's output of bioenergy during one year as being dependent of the amount of labour used on the farm that year, the quantity of capital equipment employed during that year, the amount of land under cultivation and so forth.

Supply curves for bioenergy are based on production costs of various biomass resource categories. Some studies exclude areas where attainable yields are below a certain minimum level. Other studies exclude biomass resources judged as being too expensive to mobilise, given a certain biomass price level. Costs models are based on combining land availability, yield levels and production costs to obtain plant- and region-specific cost-supply curves (Walsh 2008). These are based on projections or scenarios for the development of cost factors, including opportunity cost of land, and can be produced for different contexts and scales - including feasibility studies of supplying individual bioenergy plants and estimating the future global cost-supply curve. Studies using this approach at different scales include Dornburg et al. (2007), Hoogwijk et al. (2009), de Wit et al. (2010), and van Vuuren et al. (2009).
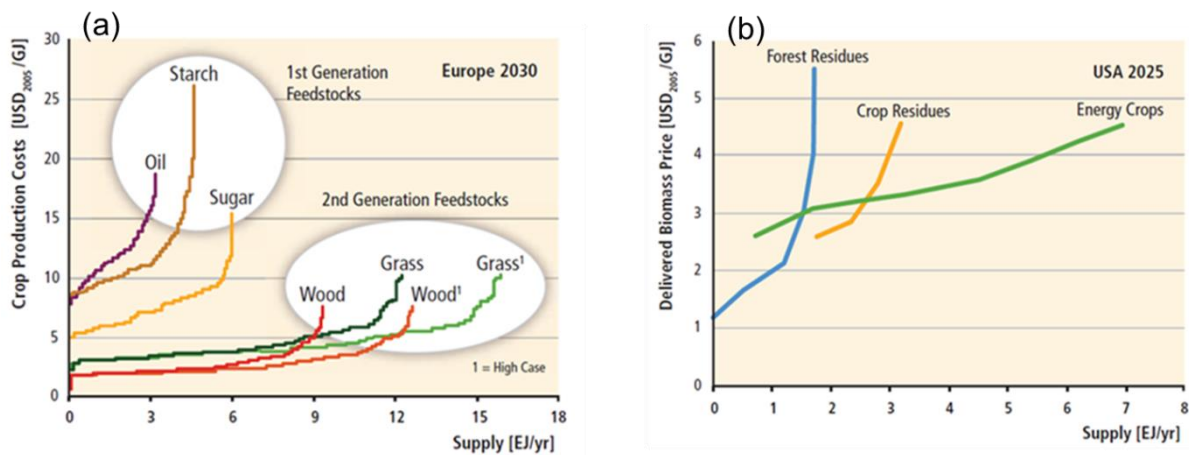
Figure 4.3 a) Feedstock Cost Supply Curve for European Countries. Source: de Wit and Faaij (2010); b) Feedstock Cost Supply Curve for the USA. Source: Walsh (2008), US DOE (2011). 1st generation biofuel supplies are expensive in Europe compared to the lignocellulosic feedstocks for the 2nd generation biofuels. USA differs from Europe in this respect.

Using biomass cost and availability data as exogenously defined input parameters in scenario-based energy system modelling can provide information about levels of implementation in relation to a specific energy system context and possible climate and energy policy targets. Estimated production cost supply curves shown in Figure 4.3a were subsequently produced including biomass plantations and forest/agriculture residues (de Wit and Faaij 2010). The key factor determining the size of the market potential was the development of agricultural land productivity, including animal production. Figure 4.3b illustrates the delivered price of biomass to the conversion facility under the baseline conditions for various production levels of lingo-cellulosic feedstock.

If regional supply curves are aggregated to form global supply curves then the biofuel trade is left out of the analysis. Figure 4.4 shows global supply curves for chosen bioenergy classes. It would be interesting to see the trade flows needed to fulfil the bioenergy needs as there are regions of ample resources and those of scarce ones. The shape of the bioenergy supply curve affects the production level assessment. If the curve is rather flat for an extended energy range then the bioenergy production level depends more on fuel demand in general and on the price levels of the competing fuels. In the flattish supply curve case only a minor change in expected price level may mean a large change in the materialising amount of bioenergy production. On the other hand, steeper supply curve narrows down the reasonable price range for a possible production level.
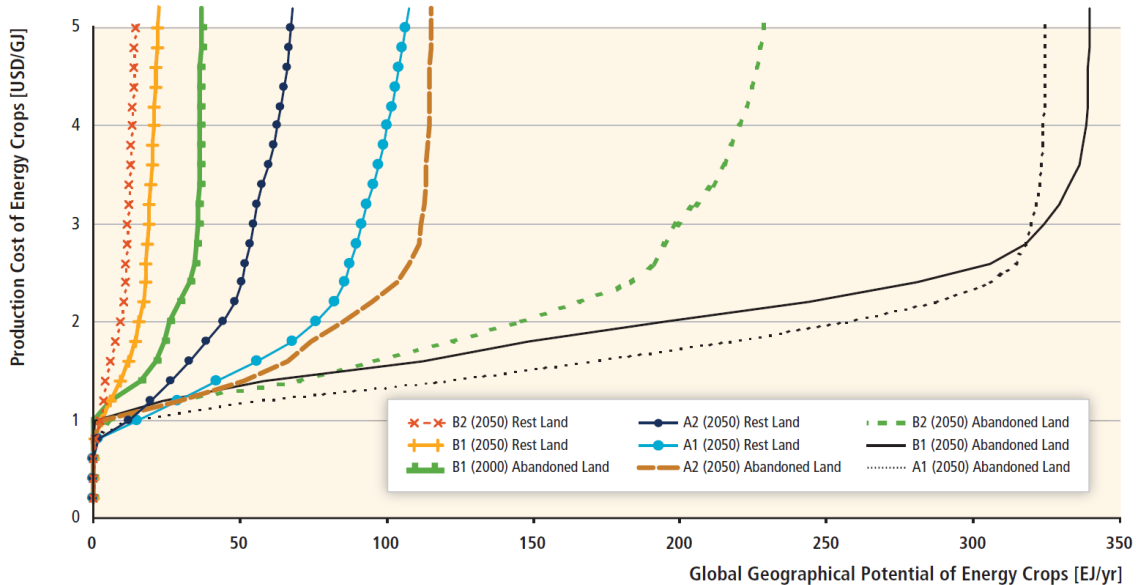
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Figure 4.4 Global Average Cost-Supply Curve for the Production of Bioenergy Plants on the Two Land Categories 'Abandoned Land' (agricultural land not required for food) and 'Rest Land' in 2050. The curves are generated based on IMAGE 2.2 modelling of four SRES scenarios. The cost supply curve for abandoned agricultural land in 2000 (SRES B1 scenario) is also shown. Source: Hoogwijk et al. (2009). The scenarios A1, A2, B1 and B2 correspond to the storylines developed for the IPCC Special Report on Emission Scenarios (IPCC 2000).

The above curves describe primary energy costs "at the farm gate". It is a convenient starting point of a bioenergy supply line. As to the local small-scale use of the product, the transportation may not add too large a share to this resource cost. But for large-scale uses, local or otherwise, the whole supply line has to be included, i.e. transportation of the resource, possible refining and transportation of the refined product to the point of use. These added production steps may be prohibitively expensive for economic use of the product no matter how large the raw material potential is.

4.1.4.3 Long-Term Deployment

Dornburg et al. (2010) breaks the potential biomass sources down into three main categories and estimates the bioenergy potential as follows:

- **Residues and wastes**

  - Agricultural and forestry residues and organic waste represent a bioenergy potential of 30-180 EJ/a. A value around **100 EJ/a** can be considered as a relatively certain estimate.

- The **surplus forest growth** that is likely to be available amounts to approximately **60**-100 EJ/a.

- **Bioenergy cropping systems** show a wide range of potential.

  - A cautious estimate for energy crop production assuming far-reaching exclusion of areas due to water scarcity, land degradation and expansion of protected areas **120 EJ/a**.

  - If water-scarce, marginal and degraded lands are not excluded but are regarded as low-quality land with low biomass yields, the additional bioenergy amounts to 70 EJ/a.

  - Improvements in agricultural management could add an additional 140 EJ/a.

Adding these categories together leads to a technical potential of up to about 500 EJ/a in 2050. Figure 4.5 presents modelling results for global primary energy supply from biomass (a) and global biofuels production in secondary energy terms (b) (IPCC 2012). Between about 100 and 140 different long-term scenarios underlie Figure 4.5. These scenario results derive from a diversity of modelling teams and cover a wide range of assumptions about - among other variables - energy demand growth, the cost and availability of competing low-carbon technologies and the cost and availability of renewable energy technologies.
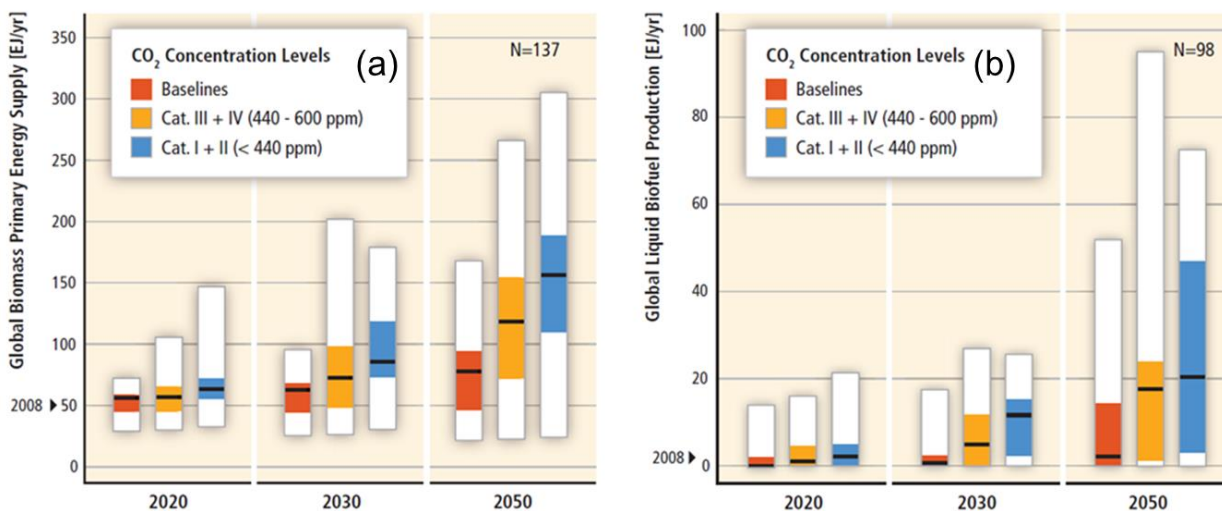
Figure 4.5 a) The Global **Primary Energy** Supply from Biomass in Long-Term Scenarios; b) Global **Biofuels** Production in Long-Term Scenarios Reported in Secondary Energy Terms of the Delivered Product (median, 25th to 75th percentile range and full range of scenario results; colour coding is based on categories of atmospheric CO2 concentration levels in 2100; the number of scenarios underlying the figure is indicated in the right upper

corner). For comparison, the historic levels in 2008 are indicated by the small black arrows on the left axis. Source: IPCC (2011).

In Figure 4.5, the results for biomass deployment for energy under these scenarios for 2020, 2030 and 2050 are presented for three GHG stabilisation ranges:

- Categories I and II (<440 ppm CO2).

- Categories III and IV (440-600 ppm CO2).

- Baselines (>600 ppm CO2).

Atmospheric CO_2 concentration is defined for the year 2100. Results are presented for the median scenario, the 25th to 75th percentile range among the scenarios, and the minimum and maximum scenario results.

Figure 4.5a shows a clear increase in global primary energy supply from biomass over time in the baseline scenarios, i.e. absent climate policies, reaching about 55, 62, and 77 EJ/a in the median cases by 2020, 2030 and 2050, respectively. At the same time, traditional use of solid biomass is projected to decline in most scenarios, which means that modern use of biomass as liquid biofuels, biogas, and electricity and H_2 produced from biomass tends to increase even more strongly than suggested by the above primary energy numbers. This trend is also illustrated by the example of liquid biofuels production shown in the right panel of Figure 4.5b.

Despite these trends, there is by no means an agreement about the precise future role of bioenergy across the scenarios, leading to fairly wide deployment ranges in the different GHG stabilisation categories. It should be noted that the net GHG mitigation impact of bioenergy deployment is not straightforward because different options result in different GHG savings, and savings depend on how land use is managed, which is a central reason for the wide ranges in the stabilisation scenarios.

The expected deployment of biomass for energy in the 2020 to 2050 time frame differs considerably between studies, also due to varying detail in bioenergy system representation in the relevant models. A key message from the review of available insights is *that large-scale biomass deployment strongly depends on*

- sustainable development of the resource base,

- governance of land use,

- development of infrastructure and

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- cost reduction of key technologies.

In the new Technology Roadmap – Bioenergy for Heat and Power IEA (2012) presents the latest views on possible bioenergy development path until 2050. According to IEA bioenergy supply increases from 50 EJ/a in 2009 **to 160 EJ/a in 2050**. These figures correspond to 10 percent of the primary energy supply in 2009 and 24 percent in 2050. Around 60 EJ of this will be allocated to transportation fuels production. The rest, 100 EJ, goes to other sectors as follows: 60 EJ for heat production in the residential, industry and other sectors. The rest or 40 EJ goes to electricity generation. This amount of bioenergy is transformed to 3100 TWh electricity. IPCC's view on bioenergy is condensed as in Figure 4.6 as follows:
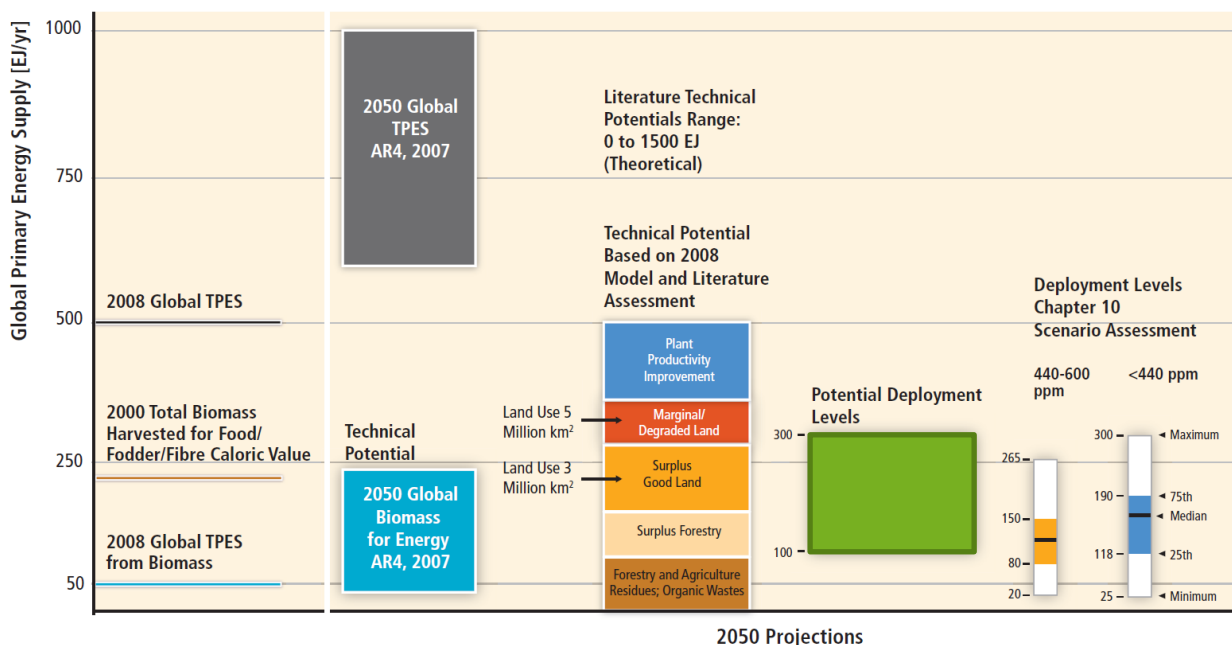
Figure 4.6 Projections for Bioenergy Use in 2050 (IPCC 2011).

It is worth noting that the bioenergy deployment estimates are substantially lower than the estimate on the technical potential. This is mainly due to the competition of bioenergy with other energy sources.

On the left-hand side of the Figure 4.6, the lines represent the 2008 global primary energy supply from biomass, the total primary energy supply (TPES), and the equivalent energy of the world's total harvest for food, fodder and fibre in 2000. A summary of major global 2050 projections of primary energy supply from biomass is shown from left to right:

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1. The global AR4 (IPCC, 2007d) estimates for primary energy supply and technical potential for primary biomass for energy;

2. The theoretical primary biomass potential for energy and the upper bound of biomass technical potential based on integrated global assessment studies using five resource categories indicated on the stacked bar chart and limitations and criteria with respect to biodiversity protection, water limitations, and soil degradation, assuming policy frameworks that secure good governance of land use (Dornburg et al., 2010);

3. From the expert review of available scientific literature, potential deployment levels of terrestrial biomass for energy by 2050 could be in the range of 100 to 300 EJ; and

4. The most likely deployment range is from 80 to 190 EJ/a.

From the expert review of available scientific literature in this chapter, ***potential deployment levels of biomass for energy by 2050 could be in the range of 50 to 300 EJ/a.*** In the most stringent mitigation case the median levels of biomass deployment appears to be 63, 85 and **155 EJ/a** by 2020, 2030 and **2050**, respectively.

As a comparison, the current total agro-forestry production corresponds to 220 EJ of which about 50 EJ is used as energy. The world population will increase somewhat by 2050 and so does food demand. The increasing bioenergy use comes on the top of that. Is there enough productive land available for all this additional production? And is the infrastructure in place to make it possible to exploit to resource in an economic way?

4.1.5 Forest Resources

4.1.5.1 Global Forest Area and Growing Stock

Basically, the availability of forest biomass for energy depends on the volume of forest resources and the other uses of forests, such as industry, biodiversity protection, and recreation, for example. The world's total forest area is more than 4 billion hectares corresponding to about 30 percent of the world's total land area (Table 4.2). The five countries most rich in forests are Russia, Brazil, Canada, the USA and China accounting for more than a half of the global forest area. The global estimated growing stock is about 527 billion m^3 (FAO 2010), which represents about 3794 EJ when transformed to energy units.

Table 4.2 Estimates for Regional Forest Areas, Growing Forest Stock and Population.

Region/country	2008 Forest area	Forest area		2010 Growing stock of forest land		2008 Population	
		from land area	from world	Over bark			Rural
	1000 ha	%	%	Mill.m^3	m^3/ha	1000 inh.	% of total
World	**4033060**	**31**	**100**	**527203**	**131**	**6 750 525**	**50**
Europe	*1005001*	*45*	25	**112052**	**111**	***731805***	***28***
Sweden	28203	69	1	**3358**	**156**	9205	16
Finland	22157	73	1	2189	119	5304	37
Germany	11076	32	0	3492	99	82264	..
Austria	3887	47	0	1135	315	8337	..
Netherlands	365	11	0	70	292	16528	18
Russia	809090	49	20	81523	192	141394	27
EU27	**156693**	**38**	**4**		**101**		
North America	**678961**	**33**	**17**	**82941**	**122**	**453543**	**19**
USA	304022	33	8	47088	155	311666	18
Canada	310134	34	8	32983	106	33259	20
Asia	**592512**	**19**	**15**	53685	**91**	**4075307**	**59**
Japan	24979	69	1	..	..	127293	34
China	206861	22	5	14684	71	1344919	57
India	68434	23	2	5489	80	1181412	71
South America	**864351**	**49**	**21**	177215	**205**	**384892**	**17**
Brazil	519522	62	13	126221	243	191972	14
Africa	**674419**	**23**	**17**	**76951**	**114**	**987280**	**61**

Source: FAO (2011).

Forest plantations form an increasing source of raw material for forest industry and they also may have an important role in carbon sequestration. In 2010 forest plantation comprised about 7 percent of total forest area (FAO 2011), and the growth rate has been fastest in South America and Asia (Table 4.3).

Globally, the annual use of wood (including industrial roundwood and wood fuel, Table 4.4) is estimated to be 3.5 billion m^3 (under bark, u.b.). Comparing this figure for global growing stock, only about 0.6 percent of the growing stock is used for production of wood fuels and industrial roundwood annually. Naturally, the percentage varies between countries, and it is the highest (6 percent) in India. According to the Faostat statistics, about the half of the global wood use, 3.5 billion m^3, is used for energy. In the emerging countries, the share is even higher.

Table 4.3 The Area of Planted Forests.

Area/country	2010 1000 ha	1990–2000 %/a	2000–2010 %/a
World	**264084**	**1,9**	**2,1**
Europe			
excl. Russia	52327	0,74	0,47
Russia	16991	1,96	1,01
Total Europe	**69318**	**1,01**	**0,6**
North America	**37529**	**4,13**	**2,46**
USA	25363	2,32	1,18
Canada	8963	15,67	4,41
Asia-Pacific	**119884**	**2,02**	**2,85**
South America	**13821**	**1,97**	**3,23**
Africa	**15409**	**1,06**	**1,75**

Source: FAO (2011).

The figures for industrial roundwood in Table 4.4 reveal the deficiency of wood in Asia and especially in China, which is a large importer of industrial roundwood. In future, the deficit

is to increase especially in India, where the high growth rates of population and economy will raise demand for forests and wood.

Table 4.4 Estimates for Regional Production and Consumption of Roundwood.

Area/country	Wood fuel		Industrial roundwood		Total	Total
	Prod.	Cons.	Prod.	Cons.	Prod.	Cons.
	Mm^3 (u.b.)	Mm^3 (u.b.)	Mm^3 (u.b.)	Mm^3 (u.b.)	Mm^3 (u.b.)	Mm^3 (u.b.)
World	**1870**	**1868**	**1626**	**1631**	**3496**	**3499**
					0	0
Europe	**134**	**132**	**508**	**492**	**642**	**624**
Excl. Russia	**119**	**117**	**373**	**378**	**492**	**495**
Sweden	6	7	66	72	72	79
Finland	5	5	46	51	51	56
Germany	11	11	45	49	56	60
Austria	5	6	14	20	19	26
Netherlands	0	0	1	1	1	1
Russia	16	15	134	114	150	129
North America	**41**	**41**	**444**	**430**	**485**	**471**
USA	40	40	298	285	338	325
Canada	1	1	147	145	148	147
Asia	**758**	**758**	325	384	1083	1142
Japan	0	0	18	23	18	23
China	185	185	144	190	329	375
India	309	309	23	23	332	332
					0	0
South America	**202**	**202**	**212**	**211**	**414**	**413**
Brazil	144	144	140	140	284	284
					0	0
Africa	**638**	**638**	**69**	**66**	707	704

Source: Faostat databank.

Most academic studies conclude that globally there is enough suitable land available to satisfy the projected global biomass demand in 2020 sustainably (Biomass for heat and power 2010). However, the current growth in biomass production in marginal lands is lower than anticipated, and there is a risk of supply shortages and increasing competition for land in areas already under intensive use.

In practice, large forest stock of a country does not necessarily indicate a large availability of wood for industrial or bioenergy use. There may be several obstacles and uncertainties pertaining to the use and mobilisation of forest resources, i.e. the demand for and supply of woody biomass, such as the activity, size, and competitiveness of forest industries, technical issues related to harvest and transport, sustainability issues and other than material values of forests, ownership structure of forest resources, etc. In the assessments of forest resource potentials, the constraints related to the actual availability of forest resources are considered in various differencing ways, a fact that contributes to the variation in estimates.

Example of Definitions and Uncertainties in Forestry Data

Wood fuel is defined in the Faostat statistics as roundwood including wood from stems, branches and other parts of trees that will be used as fuel for purposes such as cooking, heating or power production. Wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood are also included in this category. However, wood charcoal and forest industry by-products are excluded. (Faostat 2014)

When interpreting the Faostat statistics on wood fuel such as in the Table 4.4, it should be noted that some of the country figures are based on official data reported by national authorities, whereas some figures are estimates made by the experts in the FAO. A third group, aggregates, also exists and consists of figures that "may include official, semi-official and estimated data" (Faostat 2014). In the case of wood fuel, it has been difficult to obtain the figures from national statistical correspondents, and thus, estimates have been used extensively (Whiteman et al. 2002). The estimates have been based, for example, on the copied values of previous years or simple calculations based on population and the estimate for per capita wood fuel consumption. In addition to the uncertain estimates for wood fuel use by households especially in developing countries, there have also been problems to assess the non-household use of wood fuel (Whiteman et al. 2002).

Improvements towards more sophisticated estimates have been executed, yet the cautiousness is required. For example, the reported wood fuel production in Finland in 2011, 5 Mm^3 (under bark, u.b.), which is labelled as Faostat data category aggregate, corresponds roughly to stemwood used as energy in small-scale housing (5.4 Mm^3 over bark, o.b.) and energy wood (stemwood) felled in commercial fellings (0.7 Mm^3 o.b.)

(Finnish Forest Research Institute 2013). However, these figures arising in Finnish national official statistics include only stemwood for energy. Thus, branches and stumps are not included. Neither is included most of the stemwood from precommercial thinnings.

As to the consumption of wood fuel in 2011, the official Finnish statistics provide a figure of 12 Mm^3 (o.b.), which includes the use of forest chips in heating and power plants and stemwood for energy in small-scale housing (Finnish Forest Research Institute 2013). Solid industrial by-products and waste, such as bark, sawdust, and industrial chips as well as other wood residues are excluded. Also, liquid industrial waste, mainly black liquor, is excluded. Thus, the 12 Mm^3 is made of stemwood, branches, and stumps and corresponds to the Faostat definition of wood fuel. Yet, the Faostat figure for wood fuel use in Finland in 2011 is only 5 Mm^3 (u.b.). Taking the volume of bark into consideration, the official Finnish figure of wood fuel use is still twice as high as reported in the Faostat statistics. Specifically, when including also industrial by-products and waste wood, the consumption of all the solid wood fuels in heating and power plants and small-scale housing was over 23 Mm^3 in Finland in 2011 (Finnish Forest Research Institute 2013).

4.1.5.2 Wood-based Energy in the World's Primary Energy Supply

Wood based biofuels or woodfuels, as well as biomasses for energy production in general, are usually divided into traditional and modern ones. For example, the International Energy Agency (the IEA) and the Intergovernmental Panel on Climate Change (the IPCC) use such a division in their statistics and publications. The division is mainly based on the mode of using biomass. Hence, traditional biomass is primarily used inefficiently by households in cooking, lightning and heating, whereas modern biomass is used efficiently and typically in a larger-than-household scale, such as in power plants to provide heat and electricity for a factory or a community or in bio-refineries to produce transport fuels, for example.

Despite their inefficiency, the traditional woodfuels provide the majority of primary wood-based energy supply. In 2011, global primary biomass-based energy supply was 1 300 Mtoe/a (54.4 EJ/a) (IEA 2013c). This corresponded about 10 percent of total global primary energy. The distribution of primary bioenergy into various sources of biomass is presented in Figure 4.7. The shares in Figure 4.7 are based on a flow chart published originally in Sims et al. (2007), according to which in 2004, the global primary bioenergy supply was 44.6 EJ/a and accounting for a bit over 10 percent of global primary energy. Of the total primary bioenergy, 67 percent accounted for fuelwood (firewood), and with charcoal making and a part of recovered wood, traditional woodfuels accounted for 78 percent of primary bioenergy (Sims et al. 2007). The share of modern woodfuels, i.e. combined shares of forest residues, black liquor, wood industry residues and a part of recovered wood, accounted for about 13 percent of primary bioenergy. Figures provided in

Sims et al. (2007) are often cited, yet slightly differencing shares for forest residues are provided. According to Sims et al. (2007), the share of forest residues in bioenergy mix was 2 percent, whereas in IEA (2009) and Chum et al. (2011), the share of forest residues is 1 percent. This minor discrepancy does not sweep aside the fact that in 2004 and, as per an academic guess, probably also currently, the share of modern woodfuels is about 1 percent of the global primary energy supply. Despite the minuscule contribution of modern woodfuels to energy supply globally, their regional importance, current or future, are or are envisioned to be substantial.
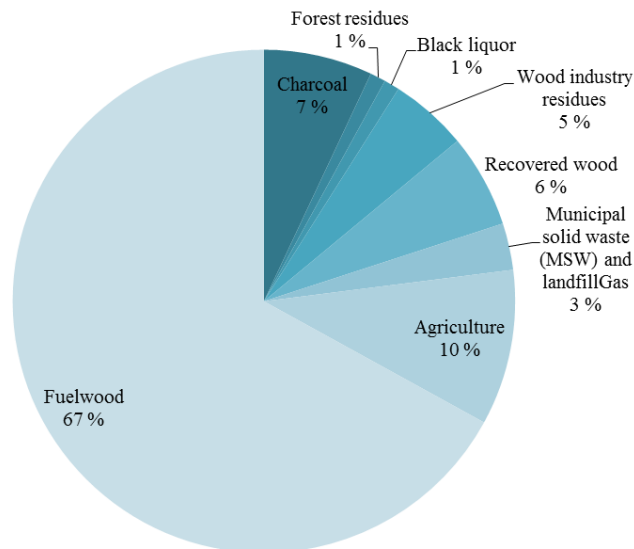

Figure 4.7 Sources of Biomass for Global Primary Bioenergy Consumption in 2004 (Chum et al. 2011, IEA 2009, original source Sims et al. 2007).

Sims et al. (2007) note that the above-mentioned biomass sources' shares in primary energy supply were based on highly uncertain data. Chum et al. (2011) also point out that especially the statistics on the traditional use of biomass are underestimates and a supplement of 20 to 40 percent should be added. This would raise the share of traditional woodfuels in total primary energy supply even higher than the above-mentioned 78 percent. As the inefficiency of energy conversion in the traditional use of biomass is obvious, Chum et al. (2011) estimate that in 2008, in terms of secondary energy delivered to end use, traditional biomass, of which over 80 percent was traditional fuelwood, accounted for 3.8–8.6 EJ/a (primary energy 37–43 EJ/a) and modern bioenergy 6.6 EJ/a (primary energy 11.3 EJ/a), of which about half was based on woody biomass.

As modern woodfuels are implicitly linked to efficient use of the energy content of woody biomass, they are of pronounced interest from the standpoint of climate change mitigation. Thus, various studies focus on the assessment the supply and demand potentials of modern woodfuels. Active research is also carried out to develop technology and

production efficiency at the different stages of bioenergy value chains based on modern woodfuels.

Definitions Related to Traditional and Modern Woodfuels

The traditional woodfuels, and traditional biomass in general, have strong negative connotations of inefficiency and underdevelopment. For example, Chum et al. (2011), who use the same definition as provided in World Energy Outlook 2010 (IEA 2010), define *traditional biomass* "as biomass consumption in the residential sector in developing countries that refers to the often unsustainable use of wood, charcoal, agricultural residues and animal dung for cooking and heating." In World Energy Outlook 2011 (IEA 2011), the definition of traditional biomass lacks the direct references to developing countries and unsustainability as traditional biomass "refers to the use of fuelwood, charcoal, animal dung and agricultural residues in stoves with very low efficiencies". Conversely, *modern biomass* is defined as biomass that is not traditional biomass. Chum et al. (2011) divide modern biomass further into *modern bioenergy* and *industrial bioenergy*. *Modern bioenergy* refers to the high-efficiency use of biomasses to generate heat, electricity, combined heat and power (CHP) and transport fuels in different sectors. Efficient use requires that convenient solids, liquids and gases are employed as secondary energy carriers. Convenient refers, for example, to the use of forest chips in CHP production. *Industrial bioenergy* is high efficiency biomass conversion into energy within industrial processes, such as steam and power generation from bark and black liquor in a pulp mill. In often cited Sims et al. (2007), woodfuels are divided into *traditional solids*, such as fuelwood (firewood) and charcoal, and into *modern solids*, such as chips and pellets, *modern liquids*, such as ethanol, and *modern gaseous*, such as syngas. The same four-category classification is also applied to agrofuels and municipal by-products and waste.

However, as pointed out by Anttila et al. (2009), terminology is not unambiguous and hence, one should be cautious, for example, when comparing the results from different studies of wood-based bioenergy. For example, terms forest energy, forest residues, woodfuel, fuelwood, and energy wood are used to describe woody biomass in energy production and different components may be included under the same terms. As an example, Anttila et al. (2009) use the term modern fuelwood to describe the use of woody biomass in large scale and in a relatively efficient way, while terms forest energy, woodfuel, and energy wood are used as synonyms for modern fuelwood. The raw material base of modern fuelwood consists of logging residues from current commercial cuttings and stemwood as well as logging residues from so called supplementary cuttings. Thus, this definition does not include industrial by-products, such as bark or black liquor nor recovered wood from previous uses and it reflects a forestry-oriented approach to wood based bioenergy particularly suitable in regions that are abundant of forest resources and have relatively well-developed forest sectors.

4.1.5.3 Primary, Secondary and Tertiary Forest Residues

The raw material base of modern woodfuels often consists of by-products, such as residues from logging operations, bark and chips from sawmilling and black liquor from pulp industry. Three main categories of forest residues, primary, secondary, and tertiary, are usually identified (e.g. Nabuurs et al. 2007, Anttila et al. 2009, Rettenmaier et al. 2010). Primary forest residues are obtained directly from forests. Thus, primary forest residues may include, for example, branches, tops, stumps, unmerchantable stemwood, and whole trees from thinnings and final fellings of merchantable stemwood often categorised as industrial roundwood. As trees can grow also areas that are not classified as forests, Rettenmaier et al. (2010) specify primary forest residues to be obtained, in addition to forest and other wooded land, such as tree plantation, from orchards, vineyards, public open spaces, and residential gardens. Nabuurs et al. (2007) also include stemwood from so called additional loggings into primary forest residues' category when discussing the assessments of forest biomass potentials. Additional loggings refer to loggings that could be executed in a particular area in addition to current level of loggings without compromising, for example, sustainability criteria. However, it seems that usually, these additional loggings or surplus forest biomass or surplus forestry products that predominantly pertain to favourable ratio of current annual removals to forest growth are not aggregated into forest residues' class. For example, in Chum et al. (2011), the additional roundwood production or so called surplus forestry products are categorised into a class of plants that are grown for energy supply and this extended classification is applied to agro biomasses (energy crops) as well.

Secondary forest residues, such as bark or sawdust, are available after processing wood into forest industry products. Tertiary forest residues are available after the end use of wood based products. Tertiary residues include consumer waste and recycled building materials, for example. Thus, the concept of recovered wood falls into this category. Research on the availability of secondary and tertiary residues has been much less active than on primary residues. One reason for this might be that, especially in the case of secondary residues, their utilisation rate is already high.

Table 4.5 Example of Categorisation of Forest Bioenergy Sources (Rettenmaier et al. 2010).

Biomass subcategory	Origin	Type of biomass
Woody biomass		
From forestry	Forests and other wooded land incl. tree plantations of short rotation forest (SRF)	Harvest from forests and other wooded land incl. tree plantations and SRF, excl. residues
From trees outside forests (landscape)	Trees outside forests incl. orchards and vineyards, public green spaces and private residential gardens	Harvests from trees outside forests incl. orchards and vineyards, excl. residues
Woody residues		
Primary residues	Cultivation and harvesting/ logging activities in all of the above incl. landscape management	Cultivation and harvesting/ logging residues (twigs, branches, thinning material), pruning from fruit trees and grapevines etc.
Secondary residues	Wood processing e.g. industrial production	Woos processing by-products and residues (sawdust, bark, black liquor, etc.)

The availability of primary and secondary forest residues is dependent on the production and wood material use of the forest industries. The production level of a sawnwood, for example, determine the amount of secondary residues, i.e. bark, sawdust, and sawmill chips available for other uses such as energy production. Production of sawnwood requires sawlogs, which can be acquired from final felling and thinning sites, from which primary forest residues, such as branches, tops, and stumps, can be collected and utilised in energy production. It should be noted that quite often, such as in Mantau et al. (2010a) and in European Commission (2013b), the term forest residues refers to primary forest residues only and thus, neither forest industry by-products nor recovered wood are included in the definition. Then again, in some biomass potential assessments forest residues of different kinds are aggregated with agricultural crop residues and waste (Sörensen et al. 1999). An example of the categorisation of the sources of woody biomass for energy production is presented in Table 4.5. As can be seen, tertiary residues are not included in the sources, yet trees – or more widely woody plants – in areas classified as forest and in areas outside forests and their primary and secondary residues, both solid and liquid, are amongst the potential sources of forest bioenergy. Short rotation forests are also considered. Thus, the variation in the sources, i.e. biomass types and their origins, of forest bioenergy can be substantial.

4.1.5.4 Energy Use of Wood Subordinate to Other Uses

As already stated in Chapter 4.1.2, energy use of biomass is not the priority when assessing biomass resources. In the case of energy use of wood, and especially modern woodfuel, the assumption is typically that the raw material needs of traditional forest industries as well as traditional use of fuelwood, are fulfilled first and after that, the woody biomass and parts of trees that are left over in the forests, mill sites, or dumps can be used in energy production and only these parts are counted into the resource potentials. In other words, stemwood that meet the requirements of industrial roundwood, such as pulpwood and sawlogs, should not be used in energy production. In the case of so called additional or supplementary or surplus loggings, industrial roundwood is included into energy potentials in some studies. The whole concept of forest residues also implicitly emphasises the idea that the energy use of wood is subordinate to other uses of wood.

The subordination of energy use to other uses of wood is understandable from the standpoint of climate changes mitigation. If a tree is felled, it is more advantageous to retain the carbon stocks of wood material in the walls of a building for decades or centuries, for example, than to release the carbon into atmosphere by combustion shortly after the felling. Also, economical reasoning is adopted when discussing the relation of energy use of wood to other uses. In several countries, paper industry has been suspecting that wood bioenergy production would be competing for pulpwood resources which would raise pulpwood prices. Accordingly, the Confederation of European Paper Industries (CEPI), for example, has been campaigning for the view that one cubic meter of wood in paper production creates multifold value added and workplaces compared to the energy use of the same cubic meter. For example in Finland, it has been next to a taboo to consider a possibility to use pulpwood in energy production. However, during the recent years, paper consumption and prices have shown a downward trend, while energy prices have been trending upwards. Logically, the straightforward reasoning by the paper industries has been challenged (e.g. Hetemäki, 2008). In the Finnish case, as wood consumption by the traditional forest industries have declined, the previous strict attitudes of interest groups to which parts of a tree can or cannot be used in energy production have been relaxed and a more all-encompassing approach to optimal use of wood raw material has emerged. Moreover, in some recent economically oriented studies on the energy use of wood, competition between energy sector and pulp industry over roundwood has been considered (e.g. Moiseyev et al. 2011, Moiseyev et al. 2013). However, in the European level political debate, the strict categorisation of different parts of wood into different uses and the absolute subordination of energy use of wood to all the other uses continues as testified by the European Commission's communication concerning the new EU forest strategy and the requirement of so called cascading use of wood (European Commission 2013c).

4.1.6 Assessment of Forest Bioenergy Resources

As to climate changes mitigation and to future sustainable low-carbon economy, forest bioenergy as well as many other renewable energy sources are loaded with expectations. It is anticipated that forest biomass would have a great potential to provide a substantial and yet sustainable source of energy – at least regionally. Ambitious political targets on the use of renewable energy sources, such as the EU's legally binding 20–20–20 targets defined in the EU RES directive (2009/28/EC), have been set based on rather limited information. In order to assess, whether the targets are feasible and to provide information for future policy building and for promoting campaigns of different interest group, several studies and reports have focused on scrutinising the amount of woody biomass that could be harvested for energy production under different assumptions and restrictions. The results, the forest energy potentials, are conditional and typically future-oriented calculations on possible, and - depending on the approach and methodology - in some specific way the maximum supply of, demand for or market equilibrium of woody biomass for energy production expressed as energy content (J or toe) or as volume (m^3).

4.1.6.1 Forest Bioenergy Potentials

The restrictions related to the calculation of the availability of forest bioenergy, or more generally bioenergy, define the kind of the potential. As discussed in the Chapter 4.1.2, three different potentials, namely, theoretical, technical, and economic potential are most commonly distinguished. In some occasions, market potential is used as synonym for economic potential (e.g. Chum et al. 2011). In addition to the definitions of potentials provided in the Chapter 4.1.2, another example of the definitions is presented in Figure 4.8.

Essentially, in the case of forests and forest biomass, the theoretical potential is the maximum amount of woody biomass production under only the most fundamental bio-physical limits, such as rainfall, soil fertility etc. However, common to most forest bioenergy potential calculations is that the volume of woody biomass available for energy use is what is left over after the traditional use of wood. Traditional use refers to industrial use of wood and to traditional woodfuel, i.e. firewood. Also, the competing use forms of land, usually food production and increasing conservation area, may be included as constraints in the calculations. Thus, the forest bioenergy potential are dependent on and subordinate to other uses of woody biomass as well as other land use forms. Moreover, the theoretical potential of primary and secondary forest residues is typically defined as their total production which, in turn, is dependent on the level of fellings and production of forest industry products (Rettenmaier 2010). Also, the use of wood products essentially limits the availability to tertiary residues. Thus, the calculated theoretical potentials of woody biomass for energy use are typically and a priori determined and restricted by several factors - most importantly the competing uses of wood - and thus they are not strictly

theoretical. Technical potential follows when theoretical potential is subjected to technical constraints. Economic or market potential is technical potential subjected to economic criteria, such as production cost, energy prices, and profit margins. Thus, the consecutive order of potentials reflects the transition from purely theoretical assessments of availability of forest bioenergy to more realistic ones.
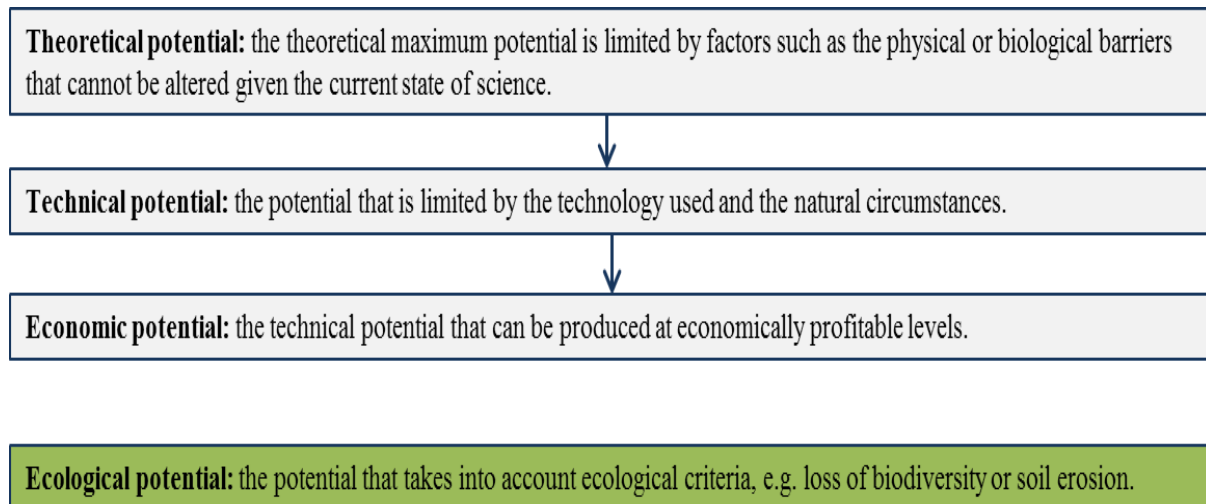
Theoretical potential: the theoretical maximum potential is limited by factors such as the physical or biological barriers that cannot be altered given the current state of science.

Technical potential: the potential that is limited by the technology used and the natural circumstances.

Economic potential: the technical potential that can be produced at economically profitable levels.

Ecological potential: the potential that takes into account ecological criteria, e.g. loss of biodiversity or soil erosion.

Figure 4.8 Example of Categorisation of Potentials (EUBIA 2013).

Although the naming and the consecutive order of the most common potentials are established, their exact definitions vary between the studies. For example, sustainably criteria or socio-political constraints can be integrated into different potentials (Figure 4.9). Moreover, additional potential categories occur in the literature. For example, EUBIA (2013) provide a category called ecological potential, yet its relation to the other three potentials is not unambiguous. In Rettenmaier et al. (2010), a potential called sustainable implementation potential is introduced. This potential is hypothesised to represent the most realistic, i.e. all the relevant restrictions considered, potential supply of bioenergy from different sources. In EEA (2006), a potential labelled as environmentally-compatible is assessed. In some cases, it is also difficult to draw clear distinctions between the potentials. As argued in Anttila et al. (2009), in some areas, the manual collection of forest residues is unprofitable due to high labour costs. Simultaneously, mechanised collection of residues cannot be integrated into fellings of industrial roundwood due to the lack of suitable machinery. Hence, in such a case, the level of mechanisation can be considered both a technical and an economic constraint. Depending on the approach used in the studies, ecological, environmental and socio-political constraints are or are not applied to the estimated potentials. Sometimes this is indicated by the naming of the potential, for example, economic-ecological or environmentally-compatible potential. However, as indicated in Figure 4.9, in some studies, environmental constraints can be included in the

technical potential, for example, whereas in some other studies, the environmental constraints are included in the economic potential only or already in the theoretical potential.
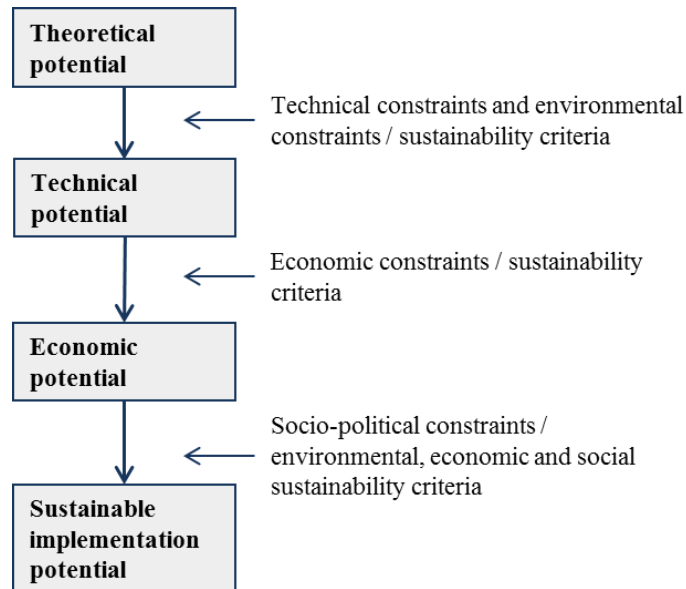

Figure 4.9 Example of Categorisation of Potentials (Rettenmaier et al. 2010).

Constraints related to different potentials and the way how the constraints are operationalised in the analyses vary between the studies. Theoretical constraints are related, for example, to forest growth which is influenced by the characteristics of site, such as soil type, climatic zone, age classes, density, availability of water, etc. Depending on the approach, factor affecting the forest growth can be considered at a detailed level, for example at tree level, or, for example regional averages are employed. In the case of primary and secondary residues, demand side characteristics, i.e. constraints related to consumption of forest industry products, such as GDP growth or structural changes in consumption patterns, which obviously are economic constraints to the material use of wood are in case of energy use also theoretical constraints. Technical constraints are related to, for example, soil bearing capacity, recovery rate of residues, energy conversion efficiency, availability of machinery etc. Environmental constraints used in the assessments include factors related to water, erosion, and soil protection, such as logging and residue extraction constraints in groundwater areas, steep slopes, and barren soils, and to biodiversity conservation, such as logging constraints in different types of conservation. Social constraints can be related to, for example, the ownership structure of forests. One may argue that in countries, where the ownership structure is fragmented and average forest holdings small, it is more difficult to mobilise wood from forests than in countries, in which the average size of forest holdings is large. Thus, many constraints

related to theoretical and technical potentials of forest bioenergy are closely related to the characteristics of forest resources or the demand side of forest bioenergy. The constraints related to economic or market potential of forest bionenergy include, harvesting and transportation costs, the prices of competing sources of energy, the price of CO_2 emission allowances, subsidies on bioenergy, etc. Economic constraints are thus closely related to the demand of forest bioenergy and forest biomass' competitiveness compared to the other sources of energy.

4.1.6.2 Assessing Forest Biomass Potential

Three different approaches to assessing the forest biomass potentials or biomass potentials in general, are typically distinguished: resource-focused (supply-driven) assessment, demand-focused (demand-driven) assessment, and integrated assessment modelling (e.g. Rettenmaier et al. 2010, Smeets et al. 2010). The approaches differ in the methodology employed as well as in the types of the potentials being assessed. In the resource-focused approach, the focus is on the resource base and the competing uses of the resources, such as the availability of land area for forests, yield of forests, and the other than energy use of woody biomass. The methodology of resource-focused assessment includes statistical analysis and spatially explicit analysis. Statistical analysis is basically based on the estimated yield per hectare and on the assumption of the fraction of woody biomass available for energy use. Social, environmental, and economic constraints may be also included in the assessment of the availability of wood for energy. The potential of forest residues (and waste wood) is based on the estimated production and use of wood which are multiplied by a residue generation coefficient, such as the biomass expansion factors (BEFs), and - as not all the residues can be collected - by a coefficient taking into account the actual recovery rates of residues. Statistically explicit analysis employs growth models to assess the yield with spatially detailed data on forests, such as forest growth, climate conditions, soil type, and forest management operations. Resource-focused approach is typically used in calculation of theoretical and technical potentials (Smeets et al. 2010).

The demand-focused approach takes into account the forest bioenergy demand side. For example, the competitiveness of bioenergy-based energy system is compared with other energy system options. Alternatively, the feasibility of the exogenously set targets on bioenergy is assessed by comparing the targets with the potential production and use of bioenergy (Rettenmaier et al. 2010). The methodology includes cost-supply analysis, economic modelling, and energy system modelling. In the cost-supply analysis, special attention is typically paid to policy measures, such as tax exemptions, the price of emission allowances, or increasing of biodiversity protection, for example. As a result, the cost-supply analysis yields bioenergy supply curves such as in Figure 4.3. The energy system modelling and economic modelling in general describe the dynamics of both the demand for and supply of energy, including bioenergy. The models incorporate different

economic fundamentals, such as population growth and GDP growth, together with possibilities related to development in energy efficiency, for example. On the demand side, the actors behave optimally by selecting the least-cost option from different energy sources, whereas the supply of energy from different sources is typically described by cost-supply curves. The demand-focused approach produces typically estimates for economic and implementation potentials (Smeets et al. 2010).

The integrated assessment modelling or integrated approach use integrated assessment models (IAMs) to address policy questions related to climate change. In a nutshell, the IAMs describe the linkages between socio-economic drivers, energy use and resulting emission to atmosphere and other pressure on environment, which cause physical changes in societies and ecosystems and eventually have a feedback to socio-economic drivers. Thus, the IAMs integrate information from various sectors, such as economic, energy, land use, and climate, and produce estimates across different time horizons and geographical units. The integrated approach typically combines results from various models and different dimensions of bioenergy are considered in an integrated manner, which distinguishes the integrated approach form the resource- and supply-driven approaches. Integrated approach is typically applied in the assessment of economic and implementation potentials, yet in the literature, also theoretical and technical potentials are assessed by using this approach. (Smeets et al. 2010).

In addition to the three above-mentioned approaches, Smeets et al. (2010) list two additional approaches: the feasibility and impact assesment and review assesment. The aim in resource-focused, demand-focused, and integrated assessments is typically to evaluate the biomass energy potential under certain constraints and assumptions, whereas in the feasibility assessment the question is, for example, whether some chosen policy target is feasible or realisable at all. The term review assessment refers to studies in which assessment of potentials in based on literature reviews and no detailed own calculations are made.

As bioenergy is loaded with expectations, a typical forest biomass potential assessment has the time horizon somewhere in future. Thus, regardless of the approach used in the assessment, some kind of scenario building and scenario analysis is typically employed. Depending on the theme of the study, scenarios may focus on the availability of forest resources under tightening competition for land area, on the response of forest growth to different climate change estimates, on the effects of various policy measures, such as binding CO_2 emission reductions, share of bioenergy in total energy consumption, price of emission allowances or on the availability and development of machinery, for example. The scenarios are typically filled with assumptions about the development of different drivers and reflect the level of knowledge during their creations and the beliefs of the makers of the scenarios. Also, aspirations and goals of different interest groups may affect the scenario building, which challenges the evaluation of plausibility of the scenarios and the interpretation of the results.

The different approaches and methodologies applied in bioenergy resource assessments have their (dis)advantages. In the demand-focused approach, the statistical analysis is typically simple, transparent, and data requirements are modest, but it ignores economic mechanisms and the level of details, for example spatially, is limited. The spatially explicit analysis is detailed spatially and climate data as well as soil characteristics can be integrated into the model, yet the economic mechanisms are ignored again. Although as a method, the spatially explicit analysis is transparent, due to the high spatial particularity, it may be a complex tool to use.

As to the demand-driven approach, the cost supply analysis is a transparent method and provides results that are typically easy interpret. However, the method ignores economic mechanisms. The energy system models and other economic models focus on the economic mechanisms, especially on the interaction of supply and demand. However, as a downside, spatially detailed results are usually not available, the integration of energy production and overall economic activity with climate change and the possible feedback to economic drivers is ignored and as are the soil characteristics and land use forms contributing to the availability of biomass. Thus, as argued by Smeets et al. (2010), the energy system models and economic models in general do not typically include bottom-up validation of bioenergy resources. Moreover, as the models may consist of a myriad of equations, which all include several parameters, the origin of which is not always known, the analyses may easily became non-transparent.

Integrated assessment modelling takes account of "all the relevant aspects" related to bioenergy production and thus, allows a consistent evaluation of scenarios having several dimensions, such as population growth, food consumption, trade flows, policy measures, and economic growth etc. A key advantage is the inclusion of feedback mechanisms and possible trade-offs in the analysis. The IAMs typically combine detailed bottom-up data on yield and land use forms with energy system models as well as other economic models and in this respect, provide probably the most appropriate approach to assess the most realistic potential of bioenergy and to evaluated the effects of bioenergy use on different sectors. However, the IAMs contain several separate models that are linked together in such a way that the output of one model is used as an input for another model, which increases the uncertainty related to inaccurate or missing data and inadequate models. In addition, as the complexity of modelling system increases, the transparency of the methodology and results suffers. Smeets et al. (2010) also point out that the results of integrated assessment modelling are difficult to interpret and the level of details is limited.

Research on the assessment of bioenergy potentials has been active during the last decade. In Smeets et al. (2010), for example, the number of studies on biomass potential assessment available for closer reviewing was some 250. However, the variation in definitions of the potentials and hence, the constraints applied in the calculations is high. Moreover, inasmuch as the approaches and methodologies used have different focuses and levels of particularity, and the level of integration of different sectors vary in the analyses, the comparison of the results between the studies is not unambiguous. The

constraints, approaches and assumptions related to analyses may reflect the focus of the study, contemporary political discussion or the aspirations of different interest groups, for example, or they are simply dictated by the quality of the data available and the methodology used. Moreover, many of the studies concentrate on the future potentials. As the time horizons of the calculation grow, assumptions related to growth of GDP, energy consumption, consumption of forest industry products, price of CO_2 emission allowances, and development of technology, for example, became critical. As an example, some estimates of forest biomass potentials are presented in Table 4.5.

As can be seen, the variation in the estimates is substantial. Even the estimates for the identically named potentials for the same region and year can be of different order of magnitude. For example, depending on the study, world's technical forest bioenergy potential originating from primary residues and surplus forest growth is estimated to be in a range of 0 to over 70 EJ/a in 2050. The most optimistic figure of the technical potential of forest bioenergy, over 1 500 EJ/a worldwide, would cover world's current primary energy consumption roughly three times. The highest figure is mainly based on the assumption that the surplus agricultural land not needed for food production would be used for growing high-yield woody bioenergy crops, such as eucalyptus, poplar and willow (Smeets et al. 2007). The figure also includes agricultural by-products and waste and it is calculated under a scenario, in which the advancement in agricultural technology is assumed to be very high, which increases the average hectare yield in agriculture multifold and swells up the availability of agricultural land for energy crops.

Smeets and Faaij (2007) identify four main reasons for the great variation in the estimates of potentials:

1) **Differences in the types of biomass included.** For example, surplus forest growth is taken into account and possibly aggregated with primary residues in some studies and in some not. Stumps may be included in primary residues or not. All the types of forest residues as well as agricultural residues may be aggregated into one group, the naming of which can be misleading at worst.

2) **Differences in the theoretical, technical, economical, or ecological constraints related to the supply of woody biomass for energy use.** This problem becomes emphasised as one moves from the theoretical potential towards the more limited types of potentials. For example, technical constraints related to rate of mechanisation and technical development or to characteristics of terrain may be considered and modelled at a spatially detailed level, or they are taken into account using some conversion factor that can be labelled as an "educated guess" at best.

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Table 4.6 Examples of Forest Bioenergy Potentials.

Region	Time frame	Potential	Estimate, EJ/a	Origin of biomass
World				
Smeets et al. (2007)	2050	technical	367–1548	surplus forest growth + primary, secondary, and tertiary residues + dedicated woody bioenergy crops on surplus agriculture land
Smeets & Faaij (2007)	2050	theoretical	76.7	surplus forest growth + primary residues
Smeets & Faaij (2007)	2050	technical	70.1	surplus forest growth + primary residues
Smeets & Faaij (2007)	2050	economic	20.8	surplus forest growth + primary residues
Smeets & Faaij (2007)	2050	economic-ecological	5.1	surplus forest growth + primary residues
Nabuurs et al. (2007)	2020–2050	technical	12–74	primary biomass from forestry
Anttila et al. (2009)	2005	technical	4.7–8.8	modern fuelwood (primary residues + surplus forest growth)
Chum et al. (2011)	2050	technical	0–110	surplus growth + primary and secondary residues
Europe				
West and East Europe: Smeets & Faaij (2007)	2050	theoretical	3.6	surplus forest growth + primary residues
West and East Europe: Smeets & Faaij (2007)	2050	technical	3.6	surplus forest growth + primary residues
West and East Europe: Smeets & Faaij (2007)	2050	economic	2.2	surplus forest growth + primary residues
West and East Europe: Smeets & Faaij (2007)	2050	economic-ecological	1.0	surplus forest growth + primary residues
EU27: Asikainen et al. (2008)	2005	technical	1.5	surplus forest growth + primary residues
EU27: Nilsson et al. (2006)	2010–2050	technical	1.8–2.2	surplus forest growth + primary residues
Finland				
Alakangas et al. (2007)	2006	technical	0.1	primary residues
Asikainen et al. (2008)	2005	technical	0.2	surplus forest growth + primary residues
Kärkkäinen et al. (2008)	2003–2013	n/a	0.5–0.7	primary residues

3) **Differences in data.** Data on key parameters and variables are uncertain or even missing. For example, figures for growth of forest, recovery rates of residues, consumption and production of forest products and woodfuel, vary between the data sources. As discussed earlier, figures from official national statistics may differ considerable from those provided in international databases.

4) **Differences in scope.** Potentials may be calculated by using either demand- or supply-driven approaches and interaction of supply and demand is ignored. The time horizons may be different as may be the assumptions related to the development of key parameters.

It can be argued, that the assumptions of the development of key parameters always reflect to some extent also the personal attitudes and feelings of the people involved in the research and the overall ambience (e.g."hype") pertaining to bioenergy. Thus, some of the estimates are implicitly inclining towards the negative, pessimistic or conservative end of the range while some estimates are more positive or optimistic.

4.1.6.3 Uncertainties Related to the Bioenergy Resource Assessments

Smeets and Faaij (2007) criticise that in several studies, uncertainties in the data and the effects of the assumptions pertaining to underlying factors are rarely paid sufficient and critical attention. Quite often, even the most elementary sensitivity analyses are not executed or if executed, they are not reported. Thus, the assessment of the validity of the results of a certain study and meaningful comparison of the results between different studies requires an in-depth analysis of the definitions, assumption, models, parameters, etc. study by study, which is time consuming and at worst, due to limited information provided in the articles, next to impossible even for a professional. Also, there exists an obvious trade-off between the sophistication and transparency of the methodology use. The inclusion of diversified aspects pertaining to bioenergy in detail requires a wide range of models describing phenomena stretching from climate change and plants reactions to changing conditions to consumer behaviour and policy measures. To fully understand the functioning of the modelling systems and the conveying of effects within several interlinked models can be demanding even for the users of the models. As the models become more complex, the number of parameters grows. Notwithstanding whether the parameter values are based on measurements, econometric analysis, simulation, guestimates etc. they always include some uncertainty, the level of which is known at best. For example, uncertainties related to GDP growth or the possible structural break in consumption of papers is discussed in earlier chapters. Then again, in the case of a simpler approach, some relevant factor may be excluded from the analysis, which can also lead to erroneous conclusions.

Obviously, when the viewpoint is purely theoretical, approaches and models which include more aspects, effects and linkages are superior to simpler ones. However, as the models became more complicated data requirements grow. Moreover, validation of the complex models may become difficult and risks related to erroneous models grow unforeseeably. For example, in Smeets et al. (2010) a myriad of bioenergy assessments ranging from simple statistical exercises to complex models encompassing supply, demand, and sustainability issues are reviewed, yet the conclusion is that "no "ideal" study using an "ideal" approach that considers all aspects in a highly adequate way has been identified." Nevertheless, the results of a study and the "ideality" of the approach used should be evaluated also in the context of the aim of the study. If the purpose is to provide a rough estimate for the theoretical potential of primary residues at a national level, for example, a simple, transparent, and labour-saving statistical analysis using aggregate data could be preferred to some complex and detailed modelling approach.

The need for harmonisation of bioenergy resource assessment has been recognised widely. For example, at the European level, the Biomass Energy Europe project focused on the harmonising of bioenergy resource assessment in order to improve the consistency, accuracy and reliability of the assessments (BEE 2011). During the BEE project, a handbook for promoting the harmonisation was produced. The learnings of the BEE project will be put into practice in the S2Biom –project (Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe, S2Biom 2014). An example of national level development of forest bioenergy assessment is the ForestEnergy 2020 project by the Finnish Forest Resource Institute and the VTT Technical Research Centre of Finland (Forest energy 2020 2014). As to improving of the statistical base of bioenergy resource assessment, the development taking place in the Faostat databank was already mentioned earlier. At national level, the Finnish Forest Research Institute is introducing statistics on energy wood trade in Finland. The novelty is that the statistics will provide detailed price and volume figures from energy wood sales between the forest owners and the first processor of energy wood. Until recently and apart from wood pellets, the price data on forest bioenergy has been available only in a few European countries, and the data has – depending on the country – consisted of only the mill gate prices of forest chips, sawmill chips, sawdust, and other solid forest industry by-products.

Development is occurring in the availability and quality of data, in modelling, in estimation techniques, in understanding of the effect of climate change on forests etc. Consequently, fresh studies of forest bioenergy and its potential will surely keep emerging. However, the reader is always left with the final responsibility of understanding among other things, what exactly has been scrutinised (e.g. technical potential of primary residues, projected actual market volumes of woody biomass for energy use), how credible are the assumptions made (e.g. development of CO_2 emission prices, development of GDP), how and in what detail the "reality" is described (e.g. the interaction of supply and demand, behaviour of firms or forest owners), and how sensitive the results might be to the changes in assumptions and parameter values. Moreover, the uncertainties related to data and

modelling should bear in mind. Thus, the reader is required to critically evaluate the validity and plausibility of the presented results and conclusions in the end. In addition to this paper, insight into the critical evaluation of the assessments can be find in the literature reviews, such as Smeets et al. (2010) and Solberg et al. (2014).

4.2 Review of Selected Forest Bioenergy Assessments and Scenarios

The political targets in different parts of the world are drivers for the use of energy from renewable sources. In the European Union (EU), the policy targets for 2020 and beyond are the main drivers for the future use of renewable energy. The policy targets indicate a significant increase in the demand for forest based energy in the EU region, which raises questions on the sufficient availability of forest biomass for energy purposes. Forest bioenergy sector is dependent on the growing forest stock and various uses of forests and wood. It interacts with climate change, biodiversity, agriculture and rural development as well as related markets.

In the following, selected studies related to forest energy are reviewed: the European (UNECE/FAO 2011), the North American (UNECE/FAO 2012) and the Russian (FAO 2012) forest sector outlook studies and the EUwood study (Mantau et al. 2010b). The purpose of the studies has been to provide information for politicians and decision makers. The selected studies have not necessarily the focus on forest bioenergy, but more widely on forests and the availability and the use of woody biomass. The aim is to provide insight into the factors contributing to forest bioenergy assessment by using the selected studies as examples.

4.2.1 Forest Sector Outlook Study for Europe

The European study (UNECE/FAO 2011) includes *a reference scenario* and four alternative scenarios emphasising *maximising biomass carbon, promoting wood energy, prioritising biodiversity and fostering innovation.* The three last mentioned policy scenarios commonly apply qualitative judgements.

The study applies quantitative models for different parts of the forest sector. At the first stage, the forest industry products supply and demand are projected up to the year 2030 by region and these figures are then fitted using Wood Resource Balance (WRB) calculation (Mantau et al. 2010b). The demand for wood energy is obtained using policy targets and trend projections (growth of 1.5 percent annually). Wood supply is projected by the EFISCEN-model (Schelhaas et al. 2007) under assumptions of future wood demand and forest management regime (rotation length, residue removals, etc.). Because the WRB-model does not take account of market adjustments, the EFI-GTM model (Kallio et al. 2004) was applied to calculate market equilibrium. The EFISCEN model was used to

estimate the effects of the market supply and demand on forestry. The modelling framework constitutes the whole chain from markets to forests, but in fact, the models are not explicitly integrated.
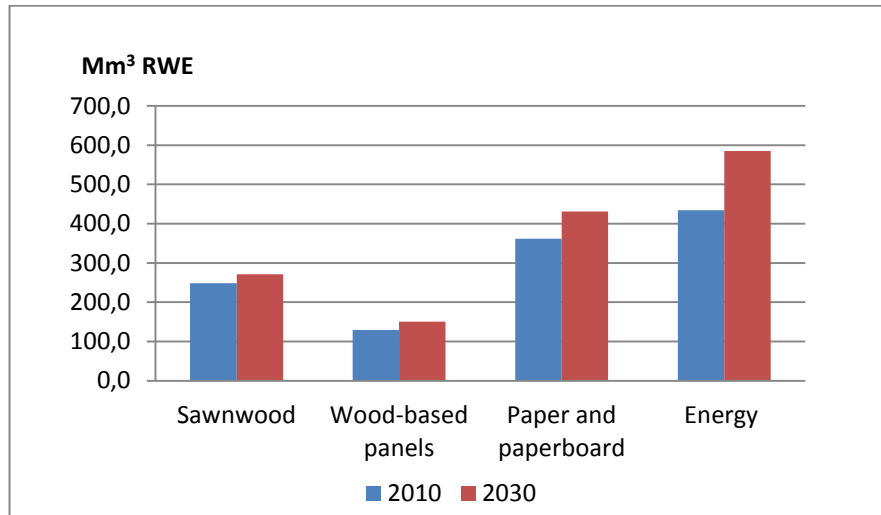

Figure 4.10 Projections of EFI-GTM for Consumption of Wood Products and Energy in the Reference Scenario, 2010 and 2030. Source: UNECE/FAO (2011).
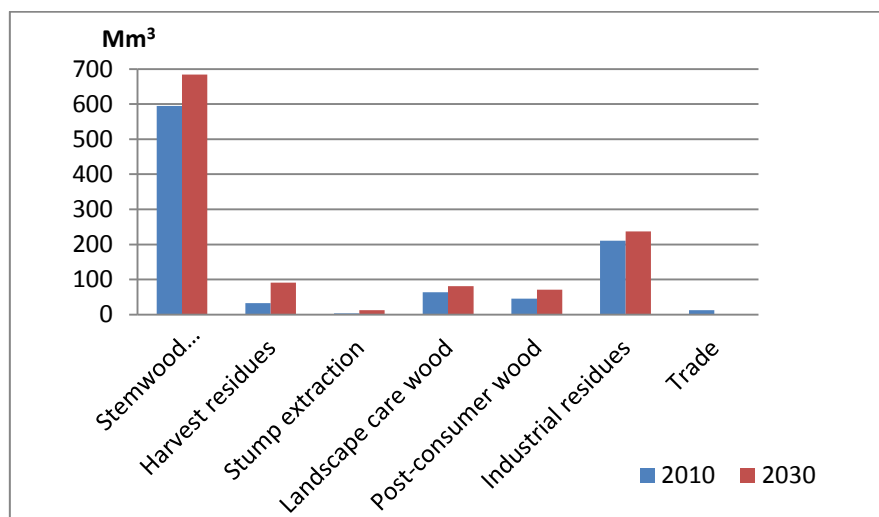

Figure 4.11 Projections for Wood Supply in the Reference Scenario, 2010 and 2030. Source: UNECE/FAO (2011).

Based on the increase in GDP, total consumption of wood products using EFI-GTM model, is projected to increase 15 percent from 2010 to 2030. Projections for different categories are presented in Figure 4.10. The projected increase in wood based energy is 35 percent. The net exports of sawnwood is decreasing, while the net exports of paper and paperboard are projected to double reaching 61 million m^3 RWE in 2030. However, for forest industry production, the results of the recent studies indicate contradictory development for paper and paperboard.

The European study assumed that the removals increase to fulfil the increasing demands for wood products and energy. The potential annual sustainable supply of wood is projected to increase about 22 per cent from 2010 to 2030. The percentage growth is projected to be the largest for stemwood and harvest residues (Figure 4.11). The European study uses different models: stemwood removals, harvest residues and stump extraction are obtained from EFISCEN-model, landscape care wood and post-consumer wood from EUwood-method and industrial residues and trade are from the EFI-GTM-model.

The policy scenarios of the European study are alternatives to the reference scenario and they focus on exploring how the forest sector could respond to the increasing demands for carbon sink, forest residues and biodiversity protection and with what consequences. *Maximising biomass carbon scenario* indicated that by lengthening rotations and increasing the share of thinnings in harvest it is possible to accumulate more carbon in European forests with minor consequences for wood supply. The *Promoting wood energy scenario* revealed that an unprecedented mobilisation of all types of wood would be needed to satisfy the increased energy targets. *Priority to biodiversity scenario* indicates no extraction at all of harvest residues, longer rotations and more mixed stands. The scenario of *Fostering innovation and competitiveness* was discussed, but no quantitative projections were made.

The projected growth of residue extraction of the whole European area is 278 percent indicating a considerable growth of intensity of harvesting methods (e.g. growth in stumps extraction) over the 2010–2030. In addition, biomass outside forests are needed in increasing amounts including supply sources such as landscape care wood, post-consumer wood, industrial wood residues (e.g., sawmill by-products, wood residues from other wood processing industries and black liquor). Estimates of their potential availability (medium mobilisation) are taken from the EUwood (Mantau et al. 2010a) and adapted for those countries not included in the EUwood study to cover EFSOS area. Net imports of wood raw material are projected to decrease from 12.6 million m^3 to 1.3 million during 2010–2030.

According to the competitiveness analysis results of the EFI-GTM model, the European countries lost their competition ability with respect to countries outside Europe (e.g., Brazil, Canada, China, Russia, USA, etc.). The prices during 2010–2030 were projected to rise steadily driven by increasing demand and emerging scarcities. For sawlogs and pulpwood the prices increases were from 1.8 to 2.7 percent annually, and for the final products 0.6–0.7 percent (sawnwood and paper) and 1.3 percent (panels). The result indicates a lower profit margin for forest industry, but higher income for forest owners.

Uncertainties related to the European study:

- The study discusses the uncertainties related to the results of the reference scenario, but no systematic modelling of uncertainties is presented.

- In the reference scenario demand for wood is gradually increasing driven by GDP growth and increasing production of forest industry products. However, the recent studies on paper and board industry production indicate decreasing demand for industrial wood. Supply or demand for wood energy is not modelled. The data are full of uncertainties. Further, in reality, demand for wood energy is volatile, and is affected by the prices of fossil energy.

- On the forest resource side, the increased demand for wood is met by increasing harvest from the forest, growing harvest residue extraction, and increase of sources outside the forest. The increases of landscape care wood and post-consumer wood are based on a range of assumptions about mobilisation, recovery rates, etc., which can be concluded very uncertain.

- Availability of residues from the industry is derived from the increasing industrial production, which can be considered very uncertain in the light of decreasing demand for paper. The supply of wood was interpreted to be sufficient to meet the demand, with fairly constant trade patterns and consumption rates. However, it was stated, that the increased demand for wood for energy is likely to lead increasing wood prices.

- The physical possibility to meet all the targets of renewable energy sustainably requires that energy efficiency targets are obtained and that rapid growth in non-wood renewable energy is met, so that wood's share of renewable energy in fact falls significantly. Wood would then account for 40 percent of renewable energy, compared to about 50 percent in 2010, as non-wood renewable energies, like solar or wind, many of which are in the phase of rapid expansion, grow faster than wood.

4.2.2 Forest Sector Outlook Study for North America

The aim of the North American Forest Sector Outlook Study (UNECE/FAO 2012) was to quantify the implications of the growth in the world's economy, population, and the bioenergy sector for the forest sectors of Canada and the United States. For modelling, the global dynamic and spatial equilibrium model of forest sector (GFPM, Buongiorno et al. 2003, Buongiorno and Chu 2011) was applied. The model takes account for interdependencies between North America, Europe and the rest of the world, and projections are made up to the year 2030.

Three IPCC based scenarios are presented (The IPCC Fourth Assessment 2007) assuming projections for population, economic growth and bioenergy production (including wood). A1B projects stronger economic and population growth (i.e. stronger growth per capita) than B2 in both countries. The third, A1B-Low Fuelwood scenario drops off the assumed growth of the use of wood in the bioenergy sector. Instead, it is assumes, that fuelwood consumed is used in its historical mix i.e., to generate heat in homes and electricity and other forms of power used in manufacturing in the forest sector. A1B-*Low Fuelwood* scenario therefore quantifies, when compared to the A1B, the net effect of assuming the high rate of growth in a wood-using bioenergy sector.

The Global Forest Products Model (GFPM) applied in the study is a spatial dynamic economic model of the forest sector. The model simulates the evolution of competitive markets for forest products in 180 countries that interact through the trade. In each country the model simulates the changes in forest area and forest stock, and the consumption, production, trade, and market-clearing prices for 14 commodity groups. For the USA, the study uses the GFPM with more disaggregated products. The base year of the model is 2006. In this application, part of the industrial roundwood may be diverted to fuelwood, then, the increasing biofuel demand raises the price of fuelwood close to that of industrial roundwood.

The GFPM – model projections suggest that the United States and Canada would, under all three scenarios, return by 2015 near the peak production levels that were observed in the early 2000s. Projections suggest that, in spite of declining use of paper for media, other paper and paperboard for packaging and miscellaneous uses will continue to enjoy strong global demand. Sawnwood production is projected to continue to grow in the United States. In wood panels, both countries are projected to increase production that can partially substitute for solid lumber, in the US building industry. The pulp and paper sector faces rapid changes: production growth outside North America, rapidly rising consumption in Asia, declining consumption of newsprint and printing and writing paper, and continued growth in the use of recycled fibre. The net effect of these changes is to keep the United States' wood pulp production from recovering much from the recently low levels. But Canada's comparative advantage and the growth of markets especially in Asia, is projected to lead increasing wood pulp production. The competitiveness of different regions was projected by applying the revealed comparative advantage index (RCA). The

RCA index is the ratio of the country's (region's) value of net exports to the value of a country's (region's) total domestic production at local prices.

Fuelwood production would increase in A1B scenario by about 5-fold (from 40 million m^3 to 205 million m^3) in the United States by 2030 (Figure 4.12). In Canada, the rise will be 7-fold (from 2.2 to 14.3 million m^3). In the B2, the rise is somewhat smaller in both countries. Under the A1B-Low Fuelwood scenario, the US fuelwood production increases very little, and somewhat faster in Canada. This indicates that the US production of fuelwood is highly dependent on the assumed emergence of a wood-based bioenergy sector. Fuelwood prices under the A1B and B2 scenarios are projected to rise in both countries from the 2006 levels. Under scenario A1B, prices slightly surpass the price of industrial roundwood. Under the A1B-Low Fuelwood scenario, where a wood-using bioenergy sector does not emerge to the degree projected by the IPCC, prices still rise in Canada, but remain virtually constant in the US.
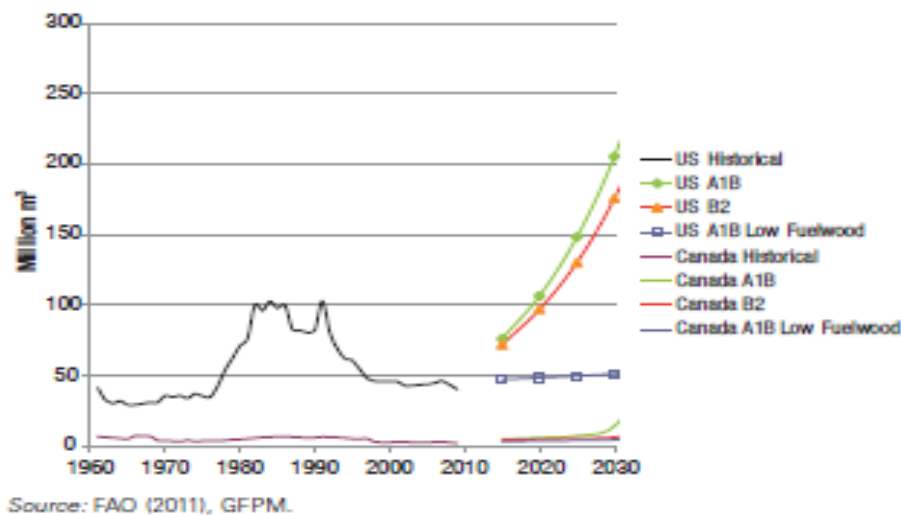

Source: FAO (2011), GFPM.

Figure 4.12 Wood Fuel Production 1961–2009 and Projections to 2030 (Figure obtained from UNECE/FAO 2012).

Wood based bioenergy is modelled as "fuelwood" in the GFPM. The wood biomass output ("fuelwood") increases 6-, 3- and 3-fold in the three scenarios, respectively, from 2006 to 2060 basing on the IPCC projections of biofuels as renewable energy source. To achieve this, the elasticity of fuelwood demand with respect to GDP was adjusted as a renewable energy source under the three scenarios. The woody biomass portion of the biofuels projection is set at a constant share, equal to the estimated 2006 share of bioenergy output provided by wood, averaged over 1990 and 2000 (Ince et al. 2011). In the modelling, Europe and North America get 100 percent of their "fuelwood" (which is the category in which it is modelled) from forests (from the merchantable and non-merchantable portion of timber removed upon harvest). In other countries, this wood can

also come from residuals of wood product manufacture (e.g., lumber residuals). Trade occurs in fuelwood, especially later in the projections.

Uncertainties related to the North American study:

- The simulation of the wood-based energy sector missed certain important factors, such as incentives (taxes or subsidies), the creation of a carbon emissions trading system, technical innovations, or a possible market-driven changes that could affect the profitability of wood-based energy. Profitability could rise due to higher energy prices, but go down due to increased supply of fossil energy (e.g., the effect of the US shale gas production).

- The results show that the sector would be to divert industrial wood currently used in making sawnwood, panels, and paper, thus leading to higher wood prices and lower output of products. Wood-based panels would be particularly affected as they would increase more than the price of lumber.

- The increasing consumption of wood-based bioenergy leads to higher prices of wood raw material (fuelwood and industrial roundwood), but decreasing but relatively less the price of manufactured products (sawnwood, panels, paper). This benefits forest owners, but decreases profits of manufacturers.

- One critical point in the model results is the assumption of increasing roundwood use of forest industries.

4.2.3 Forest Sector Outlook Study for Russia

The report presents an expert evaluation of the current state of the Russian forest sector and its prospects up to 2030. Several aspects are included: forest management, industry, policy, science, education, the environment, certification and legality of wood origin. Three scenarios for the forest sector are presented: *inertial, moderate, and innovation scenarios*. The conclusion is that the Russian forest sector will continue to increase production under all scenarios, but only the innovation scenario will ensure the progressive development of Russian forests based on the principles of sustainable forest management.

The inertial scenario is based on past trends over the years 1990–2010. The global financial crisis is assumed to continue and tariff increases for gas, electric energy and railway transportation may occur. No price increases for wood, forest products and construction of new pulp and paper plants are envisaged. Modernisation and reconstruction of functioning forest industry enterprises are assumed as well as the realisation of a few priority investment projects related to construction of sawmills, plywood and board factories. *The moderate scenario* presumes moderate economic development

and represents progress from the inertial to innovation stages. *The innovation scenario* assumes relatively high and stable economic growth. The economic lag of the last two decades is to be overcome.

Methods applied in the Russian study base for the most part on the expert assessments. Forecasting of Russian forest resources were based on the State Forest Inventory (SFI) and quantitative modelling using multiple correlation, where forest productivity indicator is the function of the amount of forestry financing distributed by years and scenarios, climatic changes and some restrictive factors. The study points out, that it would be necessary to calculate the economically accessible volumes of wood harvesting, which would exclude low stock wood stands and remote forests, where exploitation is not possible without considerable investment in the development of transport infrastructure.

Table 4.7 Forecasts for Russian Roundwood (Million m^3) from Different Scenarios by 2030 (FAO 2012).

	2010	2030	Change (%)
Production:			
Innovation	142,9	301,2	111
Moderate	142,9	259,4	82
Inertial	142,9	232,4	63
Exports:			
Innovation	21,2	22,8	8
Moderate	21,2	25,8	22
Inertial	21,2	28,6	35
Consumption:			
Innovation	121,7	278,4	129
Moderate	121,7	233,6	92
Inertial	121,7	203,8	67

The results of the scenarios are presented in Table 4.7. *For renewable energy,* the study presents the following strategic objectives (drivers): (1) the substitution of mineral fuel; (2) a reduction in environmental pressures from the fuel and energy sector; (3) the continuous supply of fuel to public utilities in regions with long-distance and seasonal deliveries; and (4) a reduction in fuel supply cost. Sources of wood energy are determined to be "nonstandard wood" and wood-processing residues. The domestic market is assumed to

remain the main consumer of wood-based biofuel. Export includes only pellets originating from regions where production is economically possible. Fuelwood and industrial wood residue will be mostly utilised as raw and fuel materials in regions with high forest cover where the availability of mineral energy is complicated. Energy sources of high energy value will be produced in the form of charcoal, briquettes and pellets, wood chips and wood-based liquid motor fuel (Table 4.8). An essential increase is assumed in the use of non-standard wood, fuelwood and wood residues for energy production (Figure 4.13).

Table 4.8 Production of the Main Wood Fuel Products (Table is obtained from FAO 2012).

Wood fuel products (thousand tonnes)

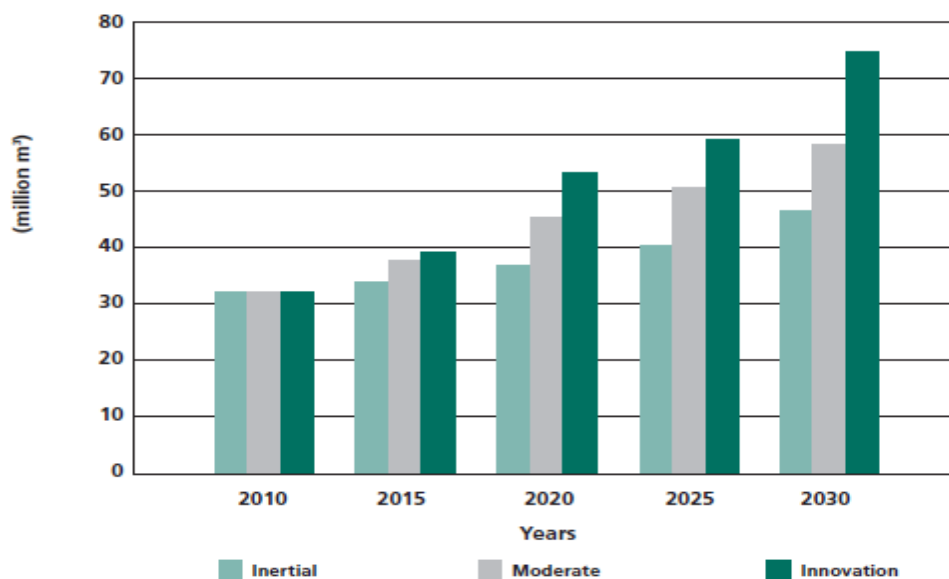| Production	2010	2015	2020	2025	2030
Charcoal	44	50	72	95	120
Briquettes and pellets	800	1 600	4 000	8 000	8 500
Wood-based liquid fuel	0	44	200	305	405

Figure 4.13 Consumption of Wood Raw Materials for Biofuel by 2030 (Figure is obtained from FAO 2012).

According to the Russian biotechnology (BIO-2020, 2012) programme, certain priorities concerning bioenergy are proposed: (1) the manufacture of solid and other biofuels; (2) technologies for combined generation of heat and power with considerable increase of electricity output; (3) wood biorefineries with combined production of cellulose, and (4) a range of new chemical products, in particular, biodegradable polymers, energy and biofuel.

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The BIO-2020 programme predicts an increase in solid biofuel production from 3 million tonnes in 2010 to 18 million tonnes by 2020.

Conclusions and uncertainties concerning the Russian study:

The study arouses a lot of concerns related to method and basic assumptions. Forecasting methods and scenarios of the study are based on expert assessments. The inertial scenario, bases on past trends, projects steady growth in forest area and growing stock, as well as harvest and consumption of forest products. The innovation scenario assumes support from all actors (e.g., the Russian state), an increase of roundwood production between 2010 and 2030, to reach over 300 million m^3 (compared to 230 million m^3 in the inertial scenario). The study expects that wood consumption for biofuels, at present 30 million m^3, would increase strongly to about 45 million m^3 in the inertial scenario, but to over 70 million m^3 in the innovation scenario. High energy value products, such as charcoal, pellets and wood based liquid fuels would grow particularly fast. Systematic calculations on the supply potential or demand developments are missing in the study. This leaves the scenario results very uncertain.

4.2.4 What Can Be Concluded from the Outlook Studies for Europe, North America and Russia?

All the studies indicate that it is possible to increase significantly the supply of wood for energy, and even to reach the ambitious policy targets. The targets for Russia are more plans than targets and systematic calculations were missing. Also for North America the targets were not clearly determined and the wood based bioenergy projections were modelled as "fuelwood" and they followed the IPCC scenarios of biofuels.

The studies indicate that especially Europe and Russia needs significant mobilisations of wood supplies through political and financial investments, if the high targets are set to increase the use of wood based energy.

The studies also stressed, that the increased use of biomass (for energy) would have negative consequences for the forest industries, notably those using small low value wood, and for biodiversity. The development can also lead to higher roundwood prices which mean increasing costs of forest industry, but forest owners would benefit higher stumpage income. Sustainability of the use of forests should be improved resolving, for example, the problem of illegal logging that is estimated by World Bank to cover about 20 percent of all the fellings. Changes in international trade of forest products and energy may have essential effects on the forest and wood based bioenergy markets. In recent years, there has been a steep increase in European imports of wood energy, in the form of chips and pellets, from other regions, notably from Canada and Russia.

- This indicates that part of the increase in wood energy supply in Europe may come from overseas in future.

- Criteria for sustainability of these overseas supplies are being put in place by the EU, to prevent its wood energy supply from being based on unsustainable sources.

An important factor, not taken into account in the studies is the development in the general energy market. Wood based energy competes with the other energy forms, such as other renewable energy (wind, water, sun, agroenergy) and fossil fuels. The latest example is the American shale gas reserves that already have had effects on the European renewable energy markets. Price relations between charcoal and wood based energy have favoured the use charcoal substituting wood based energy. In future, the price relations between different energy forms will apparently have important effects on their use.

The development of the industries based on wood fibres has effects on the availability of wood for energy. The Outlook studies discuss the demand and supply changes of paper industry, but the assumptions on its development and consequently their roundwood requirements are quite optimistic compared to the already foreseeable decreases in the demand for certain paper grades (printing and writing paper). High long-term uncertainties are related to the growth of the present form forest industry.

Further, the technology development related to the use of wood and wood materials for energy and for new materials and products will have effects on diversification of wood for different purposes. Increasing production of new wood based materials, e.g. nanofibres, and biochemicals does not necessarily increase wood consumption. In addition, producing technologies for wood based energy become more efficient.

## 4.2.5 EUwood – Real Potential for Changes in Growth and Use of EU Forests

The objective of EUwood-project was to provide a precise and reliable overview of demand for and supply of wood resources in Europe in future. Especially, the aim was a detailed and transparent estimate of future wood resource potential in Europe. The results of the project are presented in the project's final report (Mantau et al. 2010a) and in the complementing methodology report (Mantau et al. 2010b) (hereafter the EUwood study). In sum, the aim of the EUwood study is to estimate the total demand for and supply of wood in its various forms under two economic scenarios, the A1 and the B2 by the IPCC and three, namely low, medium, and, high mobilisation scenarios of wood from private forests. The different uses and sources constitute their own separate analytical modules, in which methodologies varying from econometrics to literature review and expert

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assessment are employed. The results of separate analyses are presented collectively using a tool called the Wood Resource Balance, the product of which is essentially a structured table or "balance sheet" listing the different sources and uses of wood or woody biomass. A detailed description of Wood Resource Balance and how the demand and supply potentials were estimated in the EUwood study is presented in the Appendix 2.

Table 1-4: Fact sheet on Wood Resource Balance results for Europe (EU 27)

	Wood Resource Balance				
Region	\multicolumn{3}{}{EU27}	IPCC Scenario:			A1
potential	2010	2020	2030	2010	2020	2030	demand
		M m³			M m³		
stemwood C, ME	361,8	356,8	355,7	196,4	218,5	246,7	sawmill industry
stemwood NC, ME	182,3	178,1	181,0	11,4	14,2	17,3	veneer plywood
forest residues C+NC, ME	118,0	119,8	120,3	143,3	168,4	200,3	pulp industry
bark, C+NC, ME	23,7	23,3	23,4	92,3	110,1	135,7	panel industry
landsc. care wood (USE) ME	58,5	66,0	73,5	14,8	17,6	19,8	other material uses
				20,9	43,5	53,6	producer of wood fuels
sawmill by-products (POT)	86,6	96,0	107,8	85,5	98,3	113,9	forest sect. intern. use
other ind. res. reduced (POT)	29,7	34,9	41,7	83,2	242,0	377,1	biomass power plants
black liquor (POT)	60,4	71,3	84,9	23,2	68,8	81,5	households (pellets)
solid wood fuels (POT)	20,9	43,5	53,6	154,5	163,2	150,6	households (other)
post-consumer wood (POT)	52,0	58,7	67,3	0,0	0,8	29,0	liquid biofuels
total	993,9	1.048,4	1.109,4	825,5	1.145,4	1.425,4	total

	Wood Resource Balance (without solid wood fuels)				
Region	\multicolumn{3}{}{EU27}	IPCC Scenario:			A1
potential	2010	2020	2030	2010	2020	2030	demand
		M m³			M m³		
forest woody biomass	686	678	680	458	529	620	material uses
other woody biomass	287	327	375	346	573	752	energy uses
total	973	1.005	1.056	805	1.102	1.372	total
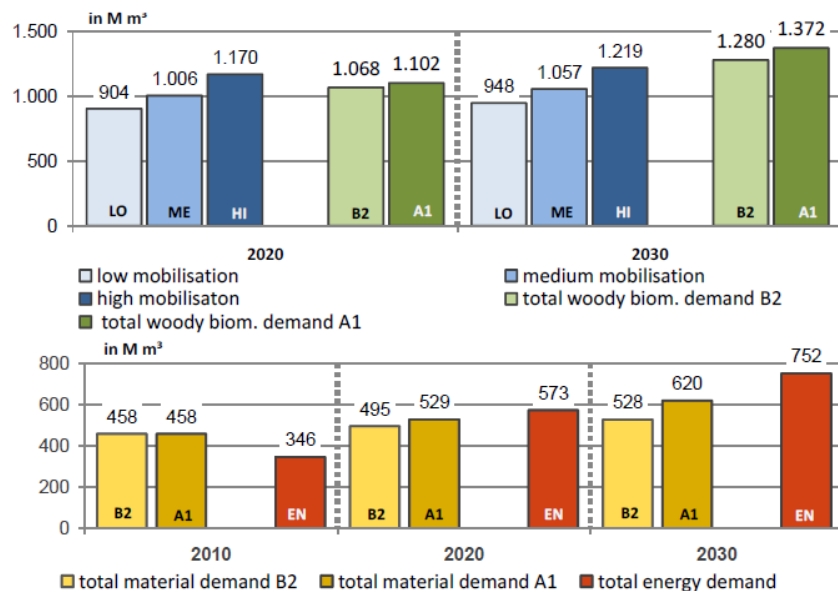
Source: Mantau, Wood Resource Balance, EUwood 2010

Figure 4.14 Wood Resource Balance for EU27 (Mantau et al. 2010a).

The estimates of potential supply of and demand for wood are presented by using the Wood Resource Balance tool. An example of the results for the EU27 is provided in Figure 4.14. According to the results, it seems that under IPCC scenario A1 potential energy demand for wood would exceed the potential material demand between 2015 and 2020. Moreover, it seems that even in the high mobilisation scenario, the potential supply of wood is inadequate to meet the potential demand for wood. Between 2010 and 2030, the material demand of wood is expected to increase by 35 percent, energy demand for wood by 117 percent in the A1 scenario, whereas supply of wood from forests decreases by 1 percent and supply of wood from other source increases by 31 per cent in the medium mobilisation scenario. In absolute terms, this development would indicate an annual gap of 316 Mm^3 between demand and supply in 2030. This computational gap and the leapt conclusion that there would not be enough wood in Europe in future is reflected in European Commissions communication to new EU forest strategy and its requirement of cascading use of wood (European Commission 2013c).

The estimates of material demand of wood are mainly based on the historical relationship between GDP growth and consumption of forest industry products and this relationship have shown signs of structural change especially in the case of paper products. Moreover, the GDP growth rates assumed in the IPCC scenarios are a bit high compared to the development since 2008. Thus, the scenarios for material use of wood may be optimistic. However, simultaneously, the scenarios for forest industry by-products to be use in energy production are positive as well.

The energy use of wood is purely based on the political decision. It is assumed that EU RES targets are reached and that wood share of the use of renewables decreases slightly. Due to the calculation procedure, it is not considered, which sources the woody biomass needed for energy production comes from. The same applies to scenarios of material uses of wood.

On the supply side, the potential supply of wood is based on the forest resource, forest growth, regulation related to fellings, as well as several technical, environmental, and social constraints. However, economic constraints and forest owners' reactions to stumpage prices, for example, are not considered. In fact, the supply of wood from forests is regarded as an administrative problem. Overall, the interaction of supply of and demand for wood is not analysed and thus, estimates of demand and supply should be interpreted separately. According the economic theory, the shifts of market price will eventually clear the markets in such a way that demand and/or supply will adjust and new equilibrium will be reached. The trade in woody biomass between the EU27 and the rest of the world is for some reason not included in the analysis, although the EU27 is a large net importer of wood. However, in the discussion of policy options, economic incentives for forest owners and possibility to import wood, for example, from Russia, are mentioned as solutions to mobilise more wood.

In the EUwood study, the different supply and demand sectors of wood are addressed and several different data sources as well as estimation techniques are employed. The approach is emphasised to be transparent and the assumptions and their effects are often discussed. However, at some points, most importantly in the case of material use of wood, sensitivity analyses are not made. The energy use of wood is based on the assumption of the fulfilment of EU RES directive's targets, but for example, the development of wood use in power plants, which is projected to increase notably, is hardly analysed. The interaction of wood supply and demand is practically completely ignored due to the procedures used in the calculations. It is mentioned, yet not actively stressed, that the calculations are describing the potential supply and demand, not the actual market volumes. Nevertheless, much effort is made to describe the supply of and demand for wood and the subcategories of supply and demand as realistically as possible. The results should be regarded as projections of what might be under the multitude of different assumptions of which probably the most important are that material use of wood develops according to the historical patterns and that EU RES targets are fulfilled and wood plays an integral role in reaching the targets.

The results of the EUwood study have gained much attention and they have also been criticised. Solberg et al. (2014) point out several shortcomings related to, for example, the assumptions of economic development and its effects on the consumption of forest industry products and the lacking description of the interaction of supply and demand and the consequent market clearance. Solberg et al. (2014) contrast the EUwood results with a few other EU level studies, and point out that such a gap in the demand for and the supply of wood simply cannot exist in a market economy. The studies included in the comparison presented in Solberg et al. (2014) employed the market modelling approach and had the aim at describing the actual volumes of wood transacted under different scenarios of price of forest chips or CO_2 emissions, for example. Critical debate is an integral part of science and obviously in the EUwood study, the description of market behaviour, for example, is far from adequate. Then again, the aim of the EUwood project was not to describe market behaviour, but to map all the relevant supply and demand potentials of woody biomass in the EU and to assess their volumes under different assumption in future. As a result, some of projected volumes, i.e. the potentials, such as the demand for material wood, may be judged as an economic potential, the energy demand for wood could be classified as something of a theoretical potential, supply of wood from forest could be labelled as technical-ecological potential, etc. Thus, when the results of EUwood project are compared with the results of a group of studies employing a rather different market modelling approach, it is – more or less – like comparing apples and oranges. Hence, a part of the criticism presented in Solberg et al. (2014) is attributable to the variety of terms, definitions, approaches, methodologies, and assumption related to the assessment of forest bioenergy and its potentials, and it points out the uncertainties and difficulties related to the comparisons of different studies.

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5 Synthesis and Implications to European Forest Bioenergy Prospects

5.1 Economic Development, Forest Industry Markets and Bioenergy

5.1.1 Economic Growth

The development and growth of the global energy consumption are highly related to the rate of the economic growth, as measured by GDP, and its distribution in the world. The economic growth rate in the long run, on the other hand, depends on the growth of population, demographic changes, migration, technical progress and structural changes in economies, among others. According to the recent projections up to 2050, the world economy as total is assessed to grow annually about 3 percent on average. This global growth, however, is distributed rather unevenly between the continents, areas and individual countries. The economic growth over the next decades in emerging economies, such as BRICS, MINT or CIVETS countries, is projected to be much faster than in mature industrialised countries. When comparing the continents, Asia, Latin and Mid-America as well as Africa to some extent are the areas which are growing fastest. Europe is assessed to regress as a slow growth area and gradually to lose its relative relevance in world economy. USA is evaluated to maintain its strong possession also in oncoming decades. China, USA, India, Brazil, Japan and Russia are assessed to be the largest economies in 2050. It is also noteworthy that the economic growth is projected to slightly slowdown over time both in emerging and developing countries.

Majority of the studies and scenarios concerning the development of the bioenergy are based on the assessments of the economic development in future. The demands of goods, like paper and board, are usually liked to GDP growth, which also defines the growth rates of industrial sectors. These assumptions, however, rely mostly on the information which was available before the economic crises in 2008. Therefore, in order to evaluate the usefulness of these bioenergy scenarios, it is important to first shortly review if the recent estimates for the economic growth up to 2030 and 2050 differ substantially and significantly from those projections made before the start of the global debt crises. Secondly, the demand of bioenergy in the scenario assessments is linked to assumed global climate policy and other regional policies. Especially, while the estimates for GDP growth in Intergovernmental Panel on Climate Change (IPCC) special reports of emissions scenarios (SRES) are most cited also in other bioenergy calculations and scenarios, it was of special interest to find out if these estimates are out-of-date and if they require reassessment and updating.

When comparing the most recent projections of economic growth rates with respect to those made before the recession and IPCC scenarios the main findings can be summarised as follows. First, the comparison is not straightforward, the results cannot be unambiguously interpreted and the projections are even somewhat contradictory. The general observation, however, is that the projections concerning

the growth in some traditional industrialised countries before the start of the economic slowdown in 2008 were slightly more positive with respect to reassessments after 2008. Similar inference can be drawn when comparing the recent projections with respect to those of IPCC's assumptions even though the GDP growth assumptions themselves vary between the different SRES scenarios. The recent forecasts concerning the annual growth of GDP seem slightly revised downwards with respect to those in IPCC scenarios. For example, the estimates for Latin America, China and most European countries are lower in OECD's (2012) report than in IPCC's scenarios. The recent estimates for the United States and India on the other hand, are in line with the IPCC scenarios. Second, the annual growth rate estimates for the US, the Russian Federation, the UK and other Western European countries are generally evaluated as slightly slower with respect to the estimates before 2008. In contrast, the studies after 2008 typically projects BRICS and MINT countries and industrialised Asia to grow slightly faster with respect to assessments before the start of recession. Third, studies both before and after 2008 project that the worldwide economic growth is gradually slowing up to 2050. Finally, the projections of the relative and rank position of the economic areas and countries up to 2030 have not changed substantially over time.

It should be noted, however, that the new IPCC emission and energy scenarios are currently being prepared, which use more recent GDP data.

5.1.2 Pulp and Paper Markets

The global and the European Union pulp and paper markets are undergoing more significant structural changes. First, for the last 7 years, in many OECD countries, the paper and paperboard production and consumption has been either stagnating or declining. The reasons behind the regressive development are both cyclical ones related to economic downturn, and structural ones related to digital media replacing the need for communication or graphics papers. However, during recent years, research on pulp and paper markets long term outlook has not been a popular topic amongst academic researchers. Thus, for many experts, the changes in the global and EU pulp and paper markets have become as a surprise. For example, the extensively cited recent projections by e.g. UNECE-FAO (2011) European forest sector outlook study (EFSOS II), Mantau et al. (2010) EUwood study, and Buongiorno et al. (2012) global and North American outlook studies project increasing consumption and production of paper products to 2030 or even 2060. In essence, the past trends are more or less projected to continue, and no structural changes are expected.

The stagnating or declining paper industry's production in Western Europe, North America and Japan will reduce the demand for pulp and pulpwood in Europe as a whole. This development has several effects on European forest bioenergy markets as well. Pulp plants are major energy producers, e.g. for district heating and paper industry. Declining pulp production will therefore decrease this type of energy

production. Secondly, the synergy and profitability gains achieved in forest biorefineries would be reduced, as, for example, the second generation biofuel production in an integrated pulp and paper mill would most likely not be attractive without the paper and pulp production. Thirdly, the procurement of pulpwood for pulp production also generates forest chips for energy production. Moreover, the income from pulpwood mobilizes forest owners to supply forest biomass to markets. Thus, these effects of declining pulp production are negative for forest bioenergy outlook in Europe. On the positive side, reduced pulp production reduces the demand and competition over forest biomass. This would improve the possibilities and profitability of forest bioenergy production.

The possibility of declining pulp production in Europe, and its impacts to forest bioenergy production in Europe, have not been addressed in research adequately. Given the above considerations, it would be important to provide a more detailed analysis of the many impacts of possibly declining pulp production. As research requires time, the most important message is currently that the actors in bioenergy markets should be prepared for the possibility of the declining pulp production in Europe.

5.1.3 Wood Products Markets

The volume of sawlog removals determines to a significant extent the availability of both industrial residues (bark, chips, sawdust) and forest residues (crowns, branches, stumps) to modern forest energy production. Therefore, the critical issues in wood products markets in terms of bioenergy potential *culminate to the volume of sawnwood markets, the indirect multiplier effects of sawlog harvesting, and the emerging possibilities to integrate bioenergy production to sawnwood production.*

The full effect of the financial crisis from 2008 onwards was not captured by most of the projections in the forest sector outlook studies, such as the EFSOS II. As a result, the sawnwood consumption projections are even tens of millions of cubic meters higher than the trend projections based on the latest available data by 2030, indicating a need for updating the scenarios.

The trend analysis for the wood products industry suggested that it would be more beneficial from the point of view of raw material availability for cascading uses and bioenergy production, if the sawnwood production and consumption would continue the trend of the period of 1992–2012, compared to the trend for the period of 2000–2012. The scenario analysis suggests that *in the rather extreme case, where the sawnwood consumption per capita would triple by 2050 and the production would be able to meet the demand, the bioenergy production from sawmilling residues in the EU27 could increase by around 90 Mm^3 from the level of 2012 (50 Mm^3) by 2050.* However, these are only rough estimates based on parsimonious data and many assumptions that could be challenged.

It is more important to think about the critical factors affecting the future volume of sawnwood consumption than producing (unreliable) quantitative estimates. According to the reviewed outlook studies, the historical trends and major demographic and economic indicators of demand do not seem to support strong growth for sawnwood markets in Europe, yet there seem to be no large threats either. However, the forest sector outlook studies consider mainly factors of general economic activity, giving less emphasis on structural factors that would affect material substitution in the construction markets, where the growth potential would be given the prospects of slow economic growth and stagnating population in Europe. Increase in the sawnwood consumption per capita would require structural changes, such as adopting industrial multi-storey construction practices also for wood-frame construction. This would probably translate into higher value added and less sawnwood production in Finland, the implications for bioenergy being fewer residues for bioenergy production on one hand, but better raw wood availability on the other hand. *Some of the critical questions can be summarised as follows*:

1) The demographic and economic developments:

   a. How much time will the recovery from the financial crisis take in Europe?

   b. Will the recession affect the industry structure (capacity vs. utilisation rate)?

2) Structural changes (substitution) in the construction markets:

   a. There are large regional differences in the consumption per capita of sawnwood across Europe: Are there opportunities for increased wood-frame construction, either in the traditional low-rise construction, or e.g. in non-residential and multi-storey sectors?

   b. Will the emphasis in the future be more towards industrial practices, and the high-end of the value chain (the role of a builder), rather than staying as a producer of basic products?

3) The competitiveness of e.g. the Finnish producers against Russia, Sweden, and Germany:

   a. How large will be the investments in Eastern Europe, Russia, and the rising giants (China, India, where also a huge bioenergy potential in by-products)?

   b. Is the potential for integrated bioenergy production in the forest industries significant enough to boost sawnwood production (significant effect on profitability)?

5.1.4 Forest Biorefinery Development

The bio-based economy is expected to grow significantly in coming next decades, and forest biorefineries will be part of this development. It seems that the hype that was related to the biorefinery business few years ago has passed, and at all the levels of the business environment more realistic plans are being made today. During the last few years the perceptions have also widened from an exploration of biorefineries from a purely technical perspective to more holistic approaches, and issues such as sustainability, socio-economic and political aspects, company strategies and evaluation of whole value chain have been taken into consideration. Currently, the biorefinery industry is at the critical stage of making the shift from pilot demonstration to successful commercial activity.

It appears that in the future there will be a range of biorefineries in different size scales utilising several types of biomass feedstock and producing variety of products. Different technologies, e.g. thermo-chemical, physical-chemical and biochemical conversion processes, will be used to provide optimal process concepts for each feedstock and product. The case-specific circumstances, such as raw material availability and prices, energy prices, regulatory conditions and the specific features of the facility with which biorefinery can be integrated will define the biorefinery model that is ultimately chosen. However, it is noticeable that the vast majority of current and planned plants at the pilot, demonstration and commercial scale, both in the EU and worldwide, are for the production of lignocellulosic bioethanol.

Many countries have potential for success in the forest biorefinery business. It also seems that countries interested in biorefinery business have many common issues that they consider in their particular strengths, therefore, realistic identification of individual, unique strengths and continuous development of competencies would be crucial at the national level.

Forest biorefineries are considered an environmentally and economically sustainable new business opportunity in many studies. Nevertheless, in addition to considerable opportunities, there are also many risks and challenges related to biorefinery implementation. Now, when many technologies are close to the stage of commercial applications, there is a need for a synthesis of current knowledge as well as for assessment of presented future prospects, potential and challenges. *What are the critical questions that should be paid emphasis on, first, by the society in general, and particularly by the companies that could transform their business models towards biorefining?*

Critical questions and challenges can be summarised as follows:

1) Competitive advantages and focus at company, sector, national and global levels:

   a. How to choose the most promising portfolios in biorefineries (Services/high value-added products/large-scale manufacturing)?

      b. Challenge: Recognising long-term competitiveness and strengths.

2) Environmental and energy policies:

      a. Challenge: Creating effective support and subsidies mechanisms for the first biorefinery facilities.

      b. Challenge: Uncertainty of policies.

3) Forest-based biomass availability and price development:

      a. Challenge: Recognising linkages with other forest-based industries (integration, by-products/waste streams/forest residues).

4) Sustainability:

      a. How to find environmentally/socially sustainable business models to realise forest biorefineries?

      b. Challenge: Lack of systematic approaches to assess environmental impacts of forest biorefineries.

5) Readiness for change and management of biorefinery consortia:

      a. How to manage strategic change towards new biorefinery business (collaboration, capabilities and resources)?

      b. Challenge: Sharing responsibilities and profits in consortia.

      c. Challenge: Recognising the role of SMEs/companies outside the traditional forest sector/novel opportunities in the interfaces of different sectors.

5.1.5 Bioenergy Potentials

Bioenergy production interacts with food, fodder and fibre production as well as with conventional forest products in complex ways. Bioenergy demand offers new markets for biomass flows that earlier were considered to be waste products. Globally biomass energy use currently amounts to approximately 50 EJ/a and all harvested biomass used for food, fodder, fibre and forest products, when expressed in equivalent heat content, equals 219 EJ/a.

Most assessments of the biomass resource potentials are variants of methodology in which biomass resource potentials are quantified under the condition that global requirements for food and conventional forest products such as sawn wood and paper are met with priority. The three main classes of biomass in the potential assessments are the following: (i) residues and wastes from agriculture and forestry; (ii) the surplus forest growth that is likely to be available; and (iii) specific bioenergy crops. The bioenergy potential ranges from 50 to 300 EJ/a.

The main uncertainties affecting bioenergy potentials are connected to food, water and biodiversity. As to food demand consumer preferences and the possibility to use alternative supply chains for protein play a major role: the change from animal to plant protein has a substantial impact on land use and water requirement. Such issues as achievable crop yields and feed conversion efficiencies in animal production are also among the main drivers of land use. Increasing yield in food production gives more possibilities for bioenergy and water scarcity affect to the other direction. The general trend in water availability is decreasing in most regions, with the largest effects in those regions where water is already scarce. However, in high latitudes it is expected that the rainfall will increase. Water demand is the other side of the water issue: the efficiency of water use in agriculture can be improved which increases biomass potential. The efficiency depends on many variables, such as crop choice, climate and agricultural practise. Large uncertainty also relates to the amount of land dedicated for sustaining the global biodiversity.

The deployment of bioenergy potential is revealed by defining and analysing future energy scenarios. This is being done quantitatively by using energy system models. These models describe how to equilibrate future energy supply and demand. The role bioenergy acquires in these analyses depends on its competitiveness in the markets.

The median estimates of the bioenergy deployment in 2050 in a comprehensive IPCC review range between 100–150 EJ/a depending on the GHG stabilisation target. The deployment range between 50 and 300 EJ/a. In most studies the deployment level stays below the maximum potential reflecting the partial non-competitiveness of the potential.

5.1.6 Forest Bioenergy Assessments and Scenarios

Climate change and the consequent policy targets aimed at greenhouse gas mitigation are the main drivers for future demand and use for energy from renewable sources. In this context, forest bioenergy is loaded with expectations. Currently, mainly due to the traditional use of fuelwood, the overwhelming majority of world's primary bioenergy consumption is based on wood. In future, the use of bioenergy is expected to grow, and for example, in the EU, ambitious targets on the use of bioenergy have been set. The expected growing demand for forest bioenergy has raised the question, whether biomass can be procured from forests sufficiently and sustainably. This question has been addressed in several reports and studies.

The assessments and scenarios of the availability and use of forest bioenergy leaves the reader puzzled. The variation in the estimates of the seemingly identical variable, such as the technical potential of forest bioenergy in the world in 2050, is exceedingly wide from the absolute zero to about 110 EJ/a, for example. The wild variation is attributable to several reasons, due to which the comparison of the results from

different studies is neither simple nor unambiguous. However, some basic guidelines to interpret, to categorise, and to evaluate the results can be given.

Typically, in the forest bioenergy assessments, the starting point is that the energy use of wood is subordinate to other uses of wood. The other uses are often defined as the use of wood by the forest industry as well as the so called traditional use of fuelwood. Thus, the availability of forest bioenergy is dependent on and limited by the other uses of wood and projections related to these. Moreover, in the assessments, much of the calculated availability of forest bioenergy is due to the primary and secondary residues, i.e. by-products of other uses of wood. There is, however, variation between the studies, how so called surplus forest growth or plantations of woody energy crops on surplus agricultural land are dealt with. For example, depending on the study, a fraction of surplus forest growth and stemwood that could be used, for example, in sawmilling, may be allowed to be used in energy production. Moreover, in some studies due to competition also stemwood that otherwise would have been consumed, for example, in pulp production can be directed to energy use. The subordination of energy use of wood to other uses of wood can be justified by targets of climate change mitigation, for example. However, one may wonder, whether such an approach with a strict a priori categorisation and allocation of different parts of wood into different use forms is necessary or even logical when, for example, dealing with theoretical potentials of forest bioenergy – figures that describe the purely hypothetical maximum availability of forest biomass for energy production. The used strict categorisation of different parts of wood into different use forms also implicitly implies non-competitiveness between energy and other uses of wood, which seems - not only theoretically but also in reality - hardly plausible.

The terminology and definitions vary between the forest bioenergy assessments. The different potentials, their exact definition, the approaches, the methodologies, and the data sets used to calculate the estimates, are to great extent study-specific. As the time frames of the studies have typically the focus in the future, the assumptions related to the development of key parameters are usually of vital importance. Work has been done to harmonise the procedures, yet projections and foresight studies in general are always essentially reflecting also the beliefs, views, and emphases of the people and interest groups involved in the studies. Thus, there is no single, predetermined right way of conducting such a study, and it remains to the reader to evaluate how credible the presented assessments and scenarios are.

Depending on the approach and the methodology, forest bioenergy assessment may include several dozens of models that are employed to calculate starting values for the next step of models. Each of the models may include several parameters, the values of which are measured, estimated, guessed, invented etc. In addition, while a part of the study matter, for example the forests physical ability to produce wood, is analysed in great detail, but then again, for example important factors affecting the actual wood supply or demand or their interaction are ignored. Although a trade-off between the complexity of the model and its transparency exists, more attention should be paid to explaining the backgrounds of the results in such an extent that at

least those who are interest could track down the very basics of the presented estimates. Despite the evident uncertainties related to parameter values and the use of models, quite often, no sensitivity analysis is executed or, at least, not reported. The effects of the uncertain parameter values or unsuitable functional forms became more severe as the time frame of the study becomes longer.

When interpreting the results of forest bioenergy assessments, one should always ask oneself among other things, what has exactly been assessed, what kind of an approach has been employed, what are the uncertainties related to the calculations, and whether these are openly discussed. For example, a calculated value of a potential, such as a technical potential, should not be interpret as a projection of actual use or supply of forest bioenergy. In the case of scenarios, projections, and more widely foresight studies, the critical evaluation of the purpose of the study is always also needed. However, it should bear in mind that the disconcerting variation in the results is hardly due to critical errors in the data, inadequate modelling or intentional manipulation, but as a result of highly complex subject matter, the energy use of the dynamically developing forest resources that can be used in several different ways and intensities and these issue can be scrutinised from several different angles having different focuses and emphasises. Thus, instead of actual numerical values of the different assessments, one should perhaps concentrate more on the development patterns and storylines presented and on the understanding how assessments and scenarios are being produced.

5.2 Conclusions

The assessment of availability, demand for, and supply of forest bioenergy, or bioenergy in general, is not a simple and unambiguous task. Moreover, when the scope is in future, the difficulties and uncertainties related to the assessments are likely to swell. In the case of bioenergy, the uncertainties related to future development are further emphasised due to fact that the main drivers affecting the supply and demand are policy measures related to the mitigation of the effects of climate change, and in policy, priorities and measures are prone to shifts.

This report aimed at providing insight into the critical factors affecting the results arising from different studies. Especially, the goal was to assist and to encourage the reader to compare, evaluate, and question the results in a critical way. The variation in estimates is wide and comparisons between studies demanding. It may seem that depending on the study, not only the magnitudes but also the signs of development of forest bioenergy availability and use are different. However, it should bear in mind that the results are always conditional to the procedures by which they were obtained. Thus, when interpreting the results, special attention should be paid, for example, to the terminology, approach, methodology, data, and assumptions employed.

In theory, the terminology related to forest bioenergy assessments may be considered rather established, yet in practise, the exact definitions of the terms vary. For example, when comparing different existing assessments of technical potential of woody biomass for energy production in the same geographical region, various environmental and social constraints may or may not be considered, not to mention the variation in the types of biomass included or in the recovery rates, for example. Moreover, one should be attentive while browsing through assessments concerning different kinds of potentials. By definition, theoretical potential has quite a little to do with actual market volumes transacted, which, in turn, may or may not be labelled as economic potentials. Moreover, due to the several differencing constraints, assumptions, data set, and approaches, the magnitudes of potentials presented in different studies are not always fully logical. For example, values of theoretical and technical potentials of forest bioenergy may be estimated to be equal in the same region and in the same year, despite the fact that by definition, the latter potential includes more constraints than the former one.

The selection of the approach and methodology is dependent on the focus of the study. When the aim is to provide as realistic as possible estimates for actual market volumes of forest residues, for example, more constraints, linkages, and assumptions have to be considered compared to the situation in which only rough estimate of theoretical or technical potential is needed. The more realistic description of demand for, supply of, and trade in forest bioenergy, the more complicated the models and the larger the data requirements. Although a seemingly sophisticated modelling approach encompassing as many as possible relevant factors affecting the phenomenon being scrutinised could be regarded superior to simpler approaches, the transparency of the approach may be jeopardised and the uncertainties pertaining to parameter values, unsuitable functional forms, and missing data, for example, may grow unforeseeable. The situation is hardly alleviated by providing neither critical discussion of possible uncertainties nor sensitivity analyses. And still, although the uncertainties could be controlled adequately, the fact remains that even the most sophisticated models are abstract simplifications that fall always short of describing the present reality, not to mention the development in future.

An example of the uncertainties related to parameter values is the global economic crisis and the consequent prolonged slowdown in the GDP growth in Europe. As in many pre-crisis forest bioenergy assessments, the IPCC A1 scenario was regarded as baseline for economic development, according to present knowledge, however, even the more pessimistic B2 scenario that was frequently used as the negative alternative for economic development may prove to be an overestimation of the GDP growth rates in Europe. As the projections for future GDP growth rates are sliding downwards, also the uncertainties related to the historical linkages between the GDP and the consumptions of forest industry products and energy are apparent. For example, due to penetration of electronic media, the relation between the consumption of graphic papers and the GDP growth is currently quite different from the 80's and 90's in many regions.

As to existing forest bioenergy assessments and scenarios a few topics are often not addressed as adequately as one would expect. *The role of new, innovative products is hardly considered or regarded as diminutive*, yet research on new material and energy products based on wood is active, expectations are high, and concrete investment decision have been made. For example, the largely reviewed IEA energy scenarios mainly expect existing industrial structures with increasing production of today's products. The carbon neutrality of wood in energy production is questioned in several forums, which may be reflected in policy measures in a way that is not promoting use of forest bioenergy. Overall, the changes in policies related to biodiversity and water protection as well as prices of competing energy sources and thus, the general acceptability and competitiveness of wood in energy production should be discussed more elaborately, as these issues are surely defining the future of forest bioenergy.

The readers and the users of forest bioenergy assessments and scenarios are confronted with a task requiring incessant attention. The point estimates, namely the numerical values, as such are handy to cite, yet without any insight into the terminology, approaches, and methodology, the numbers may easily be misinterpreted leading false conclusions. However, there are no short cuts as the use of wood in energy production is complex issue linked with several critical factors, such as energy, climate, industrial, and environmental policies, behavioural patterns of consumers and forest owners, development of technologies, international trade flows, and forests reaction to climate change.

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Table A1 Uses of Different Wood Raw Material Assortments in Forest Products and Energy Industries (modified from Indufor (2013), validated by Juha Laitila / METLA).

		Forest products						Bioenergy products				
		Sawnwood	Plywood	Pulp, Paper & Board	OSB	Particle Board	MDF	Pellets	CHP	Biofuels	Biochar	Biogas
Primary wood	Pulpwood			medium	medium	medium	medium	intensive	medium	medium	medium	medium
	Logs	medium	medium	low	low	medium	medium	medium	medium			
	Forest residues								medium	medium	medium	medium
	Small wood					low			medium	medium	medium	medium
Industrial residues	Bark								medium			
	Chips			medium		medium	medium	medium	medium	medium	medium	medium
	Sawdust			low		medium	medium	medium	medium	medium		medium
	Black liqour								medium	low		low
Recycled material	Recovered paper			medium					medium	medium		
	Recovered wood			low		medium	medium	low	medium			

Key: Black = intensive usage, Dark grey = medium usage, Light grey= low usage, White = no usage

Appendix 2.

Description of Wood Resource Balance and Estimation of Demand for and Supply of Wood in EUwood Study.

Wood Resource Balance

The basic structure of Wood Resource Balance is that the initial sources of wood are forests (forest woody biomass) and other areas (other woody biomass), whereas the users of wood are the forest or wood industry (material uses) and the energy sector (energy uses). These four basic "sectors" (forest woody biomass, other woody biomass, material uses, and energy uses) are divided into several subcomponents, which on the supply side include, in addition to coniferous and non-coniferous stemwood, also landscape care wood as well as primary, secondary, and tertiary residues. In the Wood Resource Balance, the calculation procedure is such that one solid cubic meter of wood that enters the balance sheet is, in fact, used more than one time. According to example provided in Figure A3.1, if sawmilling industry buys and uses one solid cubic meter of stemwood from forests, this one cubic meter enters both the supply or sources side ("assets") and the demand or uses side of the balance table ("liabilities"). The final product in sawmilling requires or contains 60 per cent of the wood raw material; whereas 40 per cent is sawmill by-products. This 40 per cent of the original one cubic meter of stemwood enters the supply side of the balance sheet again and it is used on the demand side of the sheet by panel industry, pulp industry, and wood fuel industry. A part of the consumption of sawmill by-products by pulp industry enters again the supply side as black liquor, and all the consumption by wood fuel industry enters the supply side as solid wood fuels. The black liquor enters then the demand side as industry internal use, whereas the solid wood fuels enter the demand side categories power and heat use and private household use. In the given example, one solid cubic meter of stemwood that entered the balance table is due to so called cascade use consumed in fact 1.53 times. The coefficient 1.53 is labelled then as cascade factor. In the methodology report, it is admitted that the calculation procedure used in the Wood Resource Balance may be considered as "double-counting", but it is also stated that the cascade use of wood should nevertheless be taken into account somehow, and when the procedure is applied properly, it does not systemically over- or underestimate either supply or demand side of the balance table, but it enlarges them both (Mantau et al. 2010b). However, when interpreting the balance table, the cascade use and its effects on the cell values, especially on the totals, must bear in mind.
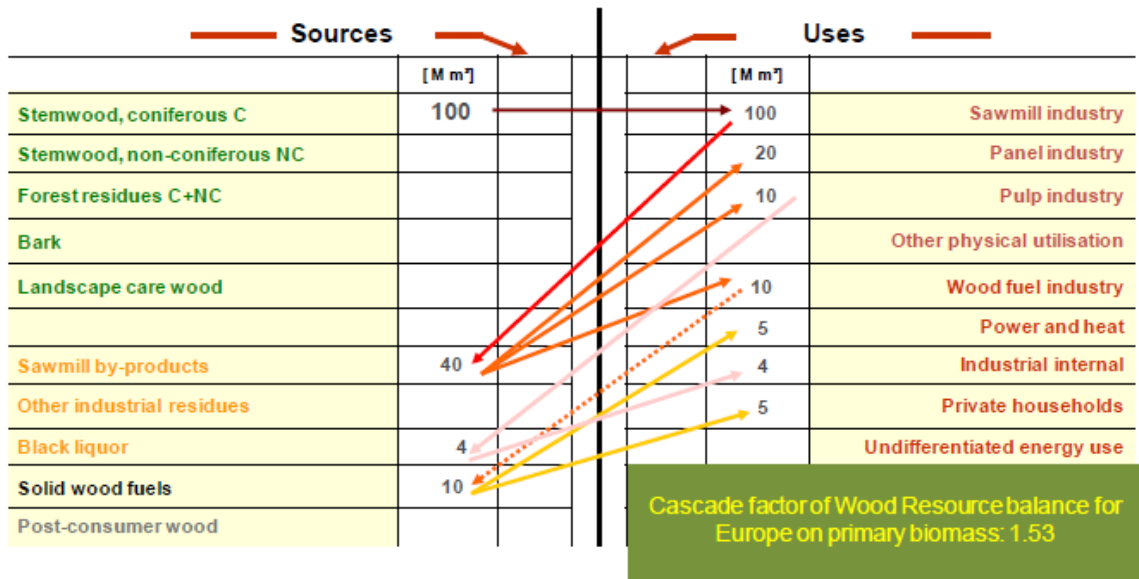
Figure A2.1 An example of Cascade Consumption of Wood in the Wood Resource Balance (Mantau et al. 2010b).
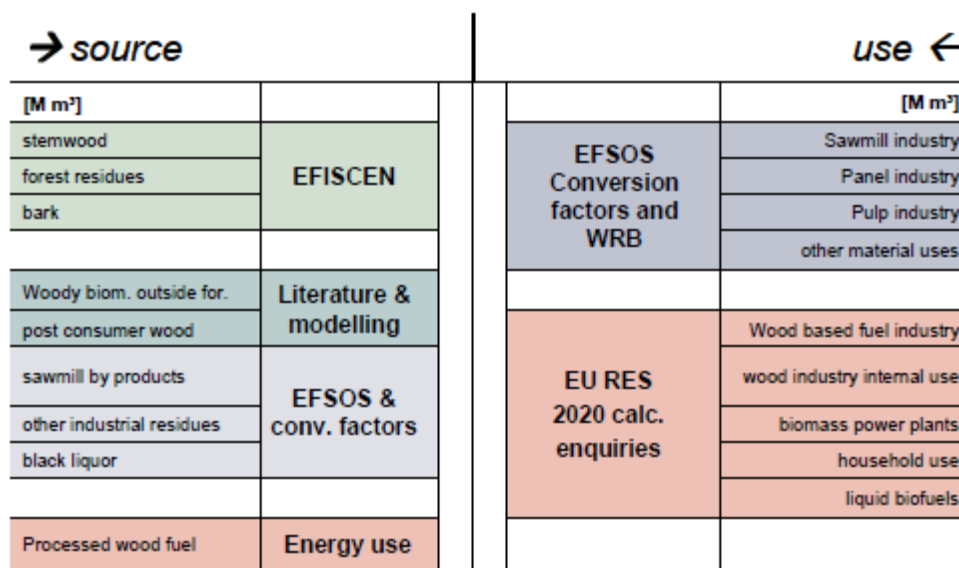

Figure A2.2 The Framework for Projections in the EUwood Project (Mantau et al. 2010b).

The availability of data required in the Wood Resource Balance varies between the countries. Data on the categories forest residues, post-consumer wood, and stemwood used by power plants are examples of imperfect national statistics. The actual supply and demand volumes can be calculated with historical data. However, the focus of the EUwood project was in the future and thus, potential supply of wood, potential demand for wood, and the projected balances were assessed for the years 2010, 2020, and 2030. Figure A3.2 depicts the different methods used to assess the

different categories of the Wood Resource Balance. As can be seen, some of the figures are based on spatially explicit modelling, econometric modelling, literature review and expert assessment. Moreover, the level of future supply of wood is assessed under three different mobilisation scenarios, and the level of future demand for wood is assessed under two economic scenarios.

Demand for wood

The demand for wood is assessed under two different scenarios, A1 and B2, based on the IPCC storylines (Nakicenovic et al. 2000) and developed to the forest sector. In brief, in the scenario A1, economic growth is steady, population growth slow, technical development in industry fast but in environment slow, global trade grows rapidly but intra-EU trade slowly, consumption of wood products rises and the concentration as well as profitability of wood based industry increases. The conversion of agricultural land into forests is to rise and employment it the countryside to fall. The A1 scenario is basically a growth scenario in an open world, in which the wood products industry is expected to thrive. As far as GDP growth figures are concerned, the A1 scenario is labelled as "business as usual".

The B2 scenario represents a world that is less global but environmentally more aware than in the A1 scenario. The growth rates of GDP and overall consumption are slower than in the A1, but the growth of population as well as the consumption of wood products faster. The concentration and profitability of wood-based industry grows slower than in the scenario A1. The conversion of agricultural land into forests is also slower than in the A1.

The IPCC scenarios and storylines employed in the EUwood study date back to the late 1990s. When applying the IPCC scenarios, in the case of GDP growth, for example, the historical, average figures from 2004–2007 were used as starting point after which the GDP growth figures provided in the IPCC scenarios were used as projections. As stated in Mantau et al. (2010b), the financial crisis and the consequent drop in the GDP growth figures are not taken into account in the scenarios. This shortcoming is justified by the authors by referring to the timing of the EUwood study: in the early 2009, no better projections were available. Similarly, also the prolonged post-financial crisis downturn in the GDP development, especially in the euro area, is ignored in the scenarios. In the A1 scenario, the annual GDP growth in EU27 is projected to be varying between 2.1–2.3 percent from 2010 to 2030, whereas in the B2 scenario the GDP growth is forecast to drop from 2.1 percent in 2010 to 1.3 percent in 2015. After a slow recovery to 1.5 percent in 2020, the GDP growth would decline to 0.7 percent in 2025 and recover again to 1.0 percent in 2030. The historical development of the GDP in EU27 in 2010–2012 shows an average annual growth rate of 1.1 percent, and if years 2008 and 2009 are included in the calculation, the average growth rate becomes negative (Eurostat). Thus, when taking the development since the beginning of financial crisis into account, even the B1 scenario seems a bit positive.

The GDP growth rates are essential in modelling the wood products demand, supply, and trade which in turn determine the material use of wood as well as availability of industrial by-products in the EUwood calculations. The material use of wood is based on econometric modelling outlined in the EFSOS study (UNECE 2005, Kangas and Baudin 2003).

The kind of econometric modelling in assessing the material demand of wood depends on the country group into which a certain country is categorised. Major markets and producers of forest products, such as Germany, the UK, Finland, and Sweden, belong to Group I. Countries that are traditional market economies, with minor production of forest products and/or relatively low consumption form the Group II, which is divided further into subgroups a, such as Denmark and Belgium, and b, such as Greece and Portugal. Countries that have their economies in transition belong to Group III, which is divided further into subgroups a and b. Multiple equations approach is then applied to the Group I countries, whereas time series cross section approach, i.e. only the demand models are estimated, is applied to the Groups II and III. The products included in the estimations are:

1. Sawnwood: coniferous and non-coniferous.

2. Wood-based panels: plywood, particle board, and fibreboard.

3. Paper and paperboard: newsprint, printing and writing paper, and other paper and paperboard.

The historical data for analyses was obtained from Faostat (production, imports, and exports), from UNECE and UN Comtrade databases (assessment of trade flows), and from FAO database (GDP and deflators). GDP projections provided by the IMF were used until 2010, after which downscaled IPCC projections (Gaffin et al. 2002) were used. The prices and cost related to the A1 and the B2 scenarios were compiled by EFORWOOD project.

In the multiple equations approach, for each product demand functions for domestically produced goods, and for imported goods as well as supply functions for domestic market and for import markets are estimated. Demand functions include domestic and import prices as well as a demand sifter, which is the development of national GDP. Supply functions of functions of domestic and export prices of the product in question, cost factors, and supply sifter, which is a variable describing the activity in export markets and defined as population weighted index of real GDP of Germany, France and Italy. All the equations are then estimated using ordinary least squares (OLS). Thus, instead of a system, the multiple equations approach consists of separate linear equations (in fact double log or log-log linear models due to logarithmic transformation of the data). In the time series cross sectional approach the demand function of a product, or more precisely the apparent consumption of the

product, is defined as a function of real domestic or import price of the product and national GDP. Contrary to the original model by Kangas and Baudin (2003), the lagged apparent consumption is not included in the regressors' list. The first yearly observations in the Forestry section of Faostat data back to 1961. The last observations used in EUwood project are from 2007. In some graphs of EUwood methodology report, the time series cover periods 1980–2007 and 1984–2007, for example. Obviously, the time series used in analyses of country groups II and III were significantly shorter than those of country group I.

According to the estimation results, there is variation of the elasticities between the countries. The elaticities have in general the corrected sing, yet in some occasions the sign is contrary to expectations. It is acknowledged that based on the data on US markets, a structural change seem to have occurred in the demand for forest products, especially papers, due to development of ICT. However, based on European data until 2007, the structural change cannot be identified.

The estimated elasticities are used in the calculation of the projected uses of different forest products and the consequent material use wood, yet the actual values of the elasticities are not reported. For each product and country, domestic and import demands and export supply projections are calculated. Domestic demand depends on domestic price and GDP, import demand depends on import price and GDP, and export supply on product price, supply sifter and costs of wood raw material. Elasticities estimated earlier are used as parameters in the projection calculations and starting values are calculated either as a five (base year 2005) or three years average (base year 2006) depending on the country group. The projections are thus simple compound interest calculations, which require in addition to base year value, the elasticities of demand, and the number of years until the date of projection also estimates for average annual growths of factors affecting supply and demand. Apart from 2008–2010, the GDP growth estimates are based on the IPCC A1 and B2 scenarios. It should be noted that the GDP growth figures by IPCC are identical in countries belonging to the same group. Countries in Western Europe belong to the IPCC country group WEU (Western Europe), whereas countries in Eastern Europe belong to group REF (countries going through economic reform). In the case the development of product prices and costs, the EFORWOOD project is referred. In the EFORWOOD, scenario calculations of mill gate prices of wood raw material at EU27 level, for example, have been made using the EFI-GTM model, which is a partial equilibrium model and describes the optimal actions of producers and consumers under perfect competition. However, it remains unclear from which study or document the used growth estimates for product prices or costs were obtained in the EUwood study and whether there is variation in the growth estimates between the countries. The used growth rates for GDP, product price, cost, and supply sifter are reported neither in the methodology report nor the final report of EUwood study.

By combining the projections for import and domestic demands for a product in a country one can calculate the projection of apparent consumption. The projection of total production is calculated by combining domestic demand for and export supply of

the product. The projected consumption and production figures are used as the basis for projections for intermediate products, wood pulp production, and, most importantly, the projections for material, i.e. solid cubic meter use of wood as well as the volumes of by-products. The calculations are based on the use of suitable conversion factors. Thus, the projections of material uses of wood are relatively simple calculations based on elasticities estimated from historical data before 2007 and projections of growth rates of GDP (and populations in case of supply sifter), product prices, and costs. The projections used in the EUwood study date back to late 1990s and early 2000s and thus the effects of the global financial crisis are not taken into account. The same applies to the structural change in the consumption of paper due to development of ICT. Even though it is apparent, that due to the compound interest calculations, the projections especially for 2030 are sensitive to parameter values, i.e. the estimated elasticities and growth rates, no sensitivity analysis is made. It should be noted that new innovative wood products and wood consumption in production of these new products are not considered in the calculations.

The energy use of wood is based on the fulfilment of the legally binding targets of the EU RES directive (2009/28/EC). The national targets for renewable energy are expressed as percentages of the total final consumption of energy, and thus projections for energy consumption are needed. However, instead of final consumption of energy gross inland energy consumption was considered mainly due to statistical reasons in the EUwood project. The gross inland energy consumption includes in addition to final energy consumption by end-users, also transmission losses as well as energy consumption by the energy sector. Initially in the EUwood study, the plan was to employ existing energy projections, such as those provided by the PRIMES project. However, as these were considered unreliable, the EUwood project made up own energy projection, which were based on the historical energy consumption and an added energy efficiency factor. The projected energy consumptions for 2020 were on an average 13 percent higher than forecasted by the national authorities of 12 member countries whose figures were available during the EUwood study. In sum, in the energy scenarios, the consumption of energy is expected to show steady decrease (-1.75–-0.5 percent depending on the country) from 2008 until 2030, and the efficiency improvement of 20 per cent is assumed to be fulfilled in 2020, after which the decrease continues steadily until 2030. Moreover, it is assumed that member countries reach their targets on the use of renewable energy sources. The result is a projection of the total use of renewable energy expressed as a share of gross inland energy consumption, i.e. not in terms of final consumption as defined in the EU RES directive. The forest bioenergy's share of the use of renewable energy is assessed firstly, by calculating a conversion factor from energy to wood (TJ/1000 m^3) using UNECE and Eurostat statistics and then applying conversion factor to the projected forest bioenergy's share of the total consumption of renewables. This calculation was based on the average national figures for 2003–2008. It was then assumed, that in the EU level the share of wood of the use of

renewables would slightly decrease until 2030 due to the expected increase in the use of solar, wind, and tide energy.

The projected total use of forest energy is then distributed to different users: industry internal use, households, liquid biofuels, and commercial heat and power production. Forest industry's internal use of energy refers, in the case of liquids, to black liquor the amount of which is dictated by the projected production of chemical and semi-chemical pulp. It is assumed that pulping technologies and the consequent need for energy need remain constant over the projection period. Furthermore, it is assumed that all the by-products from pulping are used for energy generation. As to forest industry's internal use of solid by-products, the majority is consumed by sawmills and producers of wood-based panels in drying their products. In the EUwood study, constant conversion factors expressed as m^3 of forest energy per m^3 of produced goods were. These conversion factors were partially based on UNECE figures and on uncited, empirical research carried out by Hamburg University.

Wood consumption in private households is divided into categories other and pellets and briquettes. Category other is defined as wood consumed in traditional log stoves and the national consumption figures were based either on UNECE Joint Wood Energy Enquiry 2007 or on estimates calculated in the EUwood study. The estimates are coefficients describing the fuelwood use (m^3) per rural inhabitant and their values dependent on the forest area per rural inhabitant ratio (the more forest per rural inhabitant the higher the fuelwood consumption per rural inhabitant). The projection for traditional fuelwood consumption is that the use of fuelwood would increase by 5 percent until 2015 (compared to 2010), by 7.5 percent until 2020, by 5 percent 2025, and in 2030 consumption would be in the same level as 2010. Moreover, it is assumed that 10 percent of traditional fuelwood consumption would be substituted by pellets.

The lack of statistics of pellets was evident before the beginning of 2009 when pellets were included as a separate product in the Combined Nomenclature. Thus, the EUwood projections for the use of pellets by households are based on a few observations only. High yet diminishing growth rates are assumed in such a way that pellet consumption in private in the households (EU27) – thus, pellet use in power plants s is not included – would be 23 Mm^3 in 2010, 69 Mm^3 in 2020 and 82 Mm^3 in 2030. It is admitted that the growth estimates for pellet consumption are high, but even higher estimates have been presented for example by the European Biomass Association.

In the case of liquid biofuels, the EUwood project's projections are based on the forecasts by the IEA (IEA 2009). The IEA forecasts are conservative or even sceptic concerning the possibilities of second generation wood based liquid biofuels. Nevertheless, in the EUwood study, the assumption is that half of the 6 Mtoe increase in the use of liquid biofuels in EU between 2020 and 2030 will be covered by second generation biofuels the raw material base of which is assumed to consist predominantly of wood. Furthermore, it is supposed that wood based bioenergy

consumption is covered by the productions within the EU27, but because the production is to take place in large plants, only the most forested countries, seven in total, are potential sites of the liquid biofuel production. Finally, following the IEA projection, it is assumed that 80 percent of the production of liquid biofuels is cellulosic ethanol and 20 percent thermo-chemical (biomass to liquid) conversion. According the projection, the total wood consumption in production of liquid biofuels in the EU27 would increase steeply from 1 Mm^3 (solid wood equivalents) in 2020 to 29 Mm^3 (solid wood equivalents). However, it is stated that the projection is rough and wood will possibly have a smaller role in liquid biofuels production.

The residual between the project wood consumption in energy production and the projected consumption of wood for energy by forest industry's internal use, by households, and by liquid bioenergy production, is energy production in power plants, which are labelled using the IEA terminology as the main activity producers. According to the projection, the share of power plants of the total energy use of wood grows rather steadily and in 2030 it accounts for over 50 per cent of energy use of wood. However, due to limited resources, the development of, for example, plant types and sizes are not analysed.

Sensitivity analyses of the energy use of wood are executed with respect to the fulfilment of EU RES efficiency targets, wood energy's share of total use of renewables, and conversion efficiency. The projections are quite sensitive to the fulfilment of efficiency targets and to the assumption of wood energy's share of total use of energy from renewable sources.

Supply of wood

In the EUwood project, wood or woody biomass originates from two main sources: from forests and from other sources than forests. The supply of wood from forests is defined as realisable potential for forest biomass supply. The calculation is executed in four steps. Firstly, the maximum theoretical availability of forest biomass is assessed using the EFISCEN model. Secondly, several different technical, environmental, and social constraints are applied to the theoretical availability. Thirdly, constraints related to mobilisation scenarios by the EUwood project are combined with EFISCEN calculations. Fourthly, assessment of the real potential availability of forests is executed by taking into consideration the need for workforce and machinery. Also the effects of different mobilisation scenarios on procurement costs are evaluated.

The mobilisation scenarios of the EUwood study are named high, medium, and low. In the high mobilisation scenario, it is assumed that the strong focus of forestry is on production of wood for energy and other uses. The mobilisation of wood from forest is secured by newly-established forest-owners association and high level of mechanisation. Moreover, regulations on harvesting biomass from forests are relaxed. In the medium mobilisation scenario, the harvesting potential is not exploited

in the same extent as in the high mobilisation scenario. Mechanisation is taking place, but in smaller scale than in the high mobilisation scenario. Due to biodiversity conservation, forests are protected, but the effect on harvesting remains low. In the low mobilisation scenario, the production of wood for energy and other uses is subject to environmental concerns, which leads to strict biomass harvesting guidelines. Forests are protected increasingly due to the conservation of biodiversity. Moreover, private forest owners' attitudes towards intensifying the use of forests are negative. Thus, the mobilisation scenarios are essentially administrative: whether the forest owner's association are able to induce the forest owners to follow the recommendations or not. Economic incentives, such as stumpage price and income from forests are not discussed.

The maximum theoretical potentials are calculated for coniferous and non-coniferous stemwood, logging residues (branches, tops, and needles), stumps, and early or pre-commercial thinnings. The potential of stemwood from final fellings and thinnings are calculated by using the EFISCEN model. The EFISCEN employs national forest inventory data on forest area available for wood supply, growing stock volume (m^3 o.b./ha), net annual increment (m^3 o.b./ha/a), age-classes, tree species, geographic regions, ownership classes, and site-classes. In the model, the forests are described as distribution of area over age- and volume-classes matrices. Growth dynamics, fellings, and changes in forest area are simulated by sifting forest area proportions between the matrix cells. Fellings are based on predetermined rules such as minimum age. The calculated theoretical potential of stemwood from final fellings and thinnings determine the availability of logging residues and stumps, which are calculated by using age- and species-specific biomass allocation functions and assumptions of recovery rates. The estimate for biomass from pre-commercial thinnings is not produced by EFISCEN but it is based on literature. It is implicitly assumed in the calculation of the theoretical potential of stemwood that the annual maximum harvest occurs, i.e. when thinnings or final fellings are allowed they are executed. Thus, the calculations are not projections of actual supply but projections of theoretically potential supply taking into consideration the rules applied in the calculation. It should bear in mind that in reality, the actual level of harvesting is typically something else than, for example, "the sustainable maximum". In addition, the current level or harvesting affects the future harvesting potential. For example, if the net annual increment exceeds the annual harvest and growing stock increases, this increases the harvesting potential in future (provided that the reduction of growing stock is allowed). In the theoretical calculations, the aim is typically to determine the annual maximum level of harvesting over the predetermined time span and thus, variation of this harvesting level and the effects of the variation are seldom considered.

In the EUwood project, the theoretical potentials are restricted by several technical and environmental constraints such as, slope, compaction risk, presence of peatlands, soil bearing capacity, Natura 2000 area, poor site productivity, and recovery rate, for example. Forest ownership structure and holding size are experimented as social constraints. The technical and environmental constraints

apply mainly to the availability of forest residues, stumps, and pre-commercial thinnings, whereas the availability of stemwood is restricted only by the requirement that stemwood is produced in forests available for wood production. In fact, the strictly protected areas were not included in the EFISCEN calculation in the first place. The mobilisation scenarios are implemented by varying the parameter values of certain constraints in the calculations. Economic constraints are not considered apart from the assessment of development of procurement costs in the Finnish region of North Karelia.

The effects of the constraints are significant: even with the least strict constraints in the high mobilisation scenario, the annual theoretical availability of residues is reduced from 231 Mm^3 (o.b.) to the realistic supply potential of 152 Mm^3 (o.b) at the EU27 level in 2030. In the case of stumps, the corresponding reduction is from 256 Mm^3 (o.b) to 102 Mm^3 (o.b). Sensitivity analysis reveals that in the case of medium mobilisation scenario, the assumptions related to forest owners' propensity to harvest, protected forest area, and constraints related to site characteristics (fertility and slope) have the largest impacts on the projected potential of residues and stumps. It is also discussed that the EFISCEN model, which produced the theoretical potentials, is designed for even-aged forest structure, yet 17 percent of forests in Europe could be considered uneven-aged and in some countries, such as in Italy, the share of uneven-age forests can be over 40 percent. In addition, the impacts of climate change are ignored in the EFISCEN calculations. Both the forest structure and the climate change affect the growth of forests, which essentially determine the annual theoretical potential of biomass supply. The sensitivity of the results for variation in forest growth as well as change in forest area is analysed by assuming same increases (decreases) in forest growth and area across the EU27.

Woody biomass from other areas than forests is divided into landscape care wood, short rotation coppice, recovered wood and the residues of the forest industries. Landscape care wood includes wood from urban areas such as gardens, parks, and roadsides, wood from horticulture, such as prunings and roundwood from vineyards and orchards, and wood from trees outside the forest, for example patches of trees and roadside trees in the countryside. Several sources and studies are employed in assessing the woody biomass from other areas than forest and a total potential of 86.7 Mm^3 annually is calculated from 2010 until 2030. Of the 86.7 Mm^3, 60 percent is used in energy production in medium scenario. Short rotation coppices are not included in the EUwood scenarios, due to their current small significance and the great variation in the estimates for available land area for bioenergy crops.

The sources of post-consumer wood are municipal solid wood waste mainly from households, construction waste and demolition wood, and fractions of used wood from industrial and commercial activities, such as packaging material and pallets. The availability of post-consumer wood is based on several sources and defined as a fraction of total national wood consumption.

The availability of forest industry residues is based on forest industry's production volumes. These were calculated using econometric modelling when determining the material use of wood. Calculations of forest industry residues include estimates of recovery rates, mill sizes, technologies, and vegetation characteristics, for example.