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Maarit Kallio
Antti Lehtilä
Tiina Koljonen
Birger Solberg

Best scenarios for the forest and energy sectors – implications for the biomass market

Sustainable Bioenergy Solutions for Tomorrow

CLEEN OY
ETELÄRANTA 10
00130 HELSINKI
FINLAND
www.cleen.fi

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Summary

This report documents the scenarios examined under Task 1.2.1 "Model aided business analysis" in the BEST research consortium. The task has involved modelling detailed medium- to long-term scenarios for forest and energy sectors to identify the supply and demand for bioenergy and to examine the developments in the related business environment in Finland, in the EU and globally. The focus of the scenarios is in the period up to 2030, but less comprehensive indicative results are provided up to 2050 as well. While we consider all biomass, developments concerning forest biomass are discussed in more detail.

What all three scenarios have in common is that the use of biomass for energy is projected to increase considerably in the future. The main driver for this development is the decreased competitiveness of fossil fuels either due to their high prices as such or due to their high use costs caused by tightening climate policies. In particular, there is a need to take in use quickly applicable solutions for shifting the transport sector from using fossil fuels to renewable energy. In the regions where the use of solar and wind power will become increasingly important for power supply, biomass provides options for power system reserves and regulating power. In the long run, bioenergy may provide possibilities even to achieve negative emissions through bio-CCS –technologies (i.e. BECCS). Such option is valuable, because in some sectors, like in agriculture, emissions can be hard to cut down.

In the global and European level, majority of the energy biomass is projected to come from agricultural sector. Despite that, the amount of forest chips and round wood used to produce heat, power and liquid biofuels increases drastically. In order to satisfy this demand for energy wood in sustainable manner, it is essential that planted area of fast growing forests increases and that a shift from household fuel wood burning to modern energy technologies takes place to a large extent. In Finland, forest biomass continues to play the most important role not only in the biomass supply, but also among the renewable energy sources.

In some scenarios, 80–90% of the biomass potential that has been perceived to be sustainably available is in the use by 2050. Although this biomass was considered sustainably available according to the data, the projected development might bring in conflicts with the other uses of biomass and land, which could alternatively supply food, biomass for material needs, and environmental services. Furthermore, the scarcity of biomass may become an issue in a local level, despite not appearing problematic when looked at a larger scale. These issues call for technical development and innovations in all fronts.

Helsinki, June 2015

Contents

1 Introduction

This report documents the scenarios examined under Task 1.2.1 “Model aided business analysis” in the Sustainable Bioenergy Solutions for Tomorrow (BEST) research work. Three scenarios were defined to examine the supply of and demand for biomass under selected policies and technological development paths. The emphasis was placed on wood biomass, but the energy system analyses covered basically all bioenergy options.

The work supplements the qualitative scenario work reported in the BEST programme 2014 (Kettunen & Meristö 2014). From the abundant material, three future paths were chosen for further elaboration and analysis. The choice was made on the basis of the goal of having a diverse enough representation of potential future development of the societies and energy systems used. Yet, the scenarios studied here do not overlap one to one with those reported by Kettunen and Meristö. The global forest sector model EFI-GTM (Kallio et al. 2004) and the global energy systems model TIMES-VTT (Lehtilä et al. 2014) were used to quantify the market impacts of the scenario assumptions.

In the analysis, we focused on forest and wood-based biomass due to its importance to the goals and opportunities of the users and suppliers of Finnish bioenergy cluster, including energy and forest industries, new technology developers, and related service providers. Yet, also the supply of and demand for agricultural biomass resources are accounted for in the model simulations for global energy markets. The main focus in the analysis is the period 2010–2030, but because the investments both in the energy and forest sector are typically made for longer time period, and so are the climate targets to tackle the climate change, we also scanned the developments after 2030 up to 2050. In the geographic scope, we discuss the results for Finland and Europe (here: The European Union, Norway and Switzerland) in more detail, but also comment the developments globally.

According to the IEA Energy Statistics, bioenergy has accounted for roughly 10% of global total primary energy supply since 1980 (IEA 2014). Between 1980 and 2010 bioenergy supply increased from 31 to 55 EJ, along with the increasing global energy demand and new policies and measures to increase the use of renewable energy sources in both OECD and non-OECD-countries. In 2012, renewable energy accounted for only 13% of the world primary energy supply. Solid biofuels represented 69% of all renewable energy, and wood accounted for about 65% of the solid biofuels. Liquid biofuels, mainly for the transport sector, represented about 4% of renewable energy, and biogas only about 1.5%. Liquid biofuels and biogas have been the highest growing components of the primary bioenergy supply. However, liquid biofuels are, in fact, usually produced from solid biomass, and in this study the reporting is based on the primary feedstock biomass.

In future, the use of bioenergy has been projected to increase considerably due to tightening climate targets and because bioenergy is usually a local energy source, which enhances the security of energy supply and also has positive impacts on local economy. Especially modern uses for power and heat production and liquid biofuels production are expected to increase but there are large uncertainties related future policies on sustainability and land use (i.e. ILUC and LULUCF policies), competition of the biomass raw material between material and energy use, competitiveness of bioenergy against other clean energy technologies, and also public acceptance of bioenergy vs. other technologies.

Global bioenergy potentials have been estimated to be many times higher than the current levels of consumption, but the expanding demand for bioenergy mainly comes from increased use of energy crops and other field biomass. Therefore the increased use of bioenergy and biofuels for transport may also raise serious questions about the sustainability of bioenergy supply especially if the crowing potential is having negative impacts on food and feed production or their market prices. In this study, an attempt was made to use such estimates for the global and regional bioenergy potentials that, according to most studies, would correspond to levels that can be produced in a sustainable way, both globally and in Finland.

2 Modeling methodology

2.1 Forest sector model

The global forest sector model EFI-GTM (Kallio et al. 2004) was used to quantify the market impacts of the scenario assumptions on the forest sector.

The EFI-GTM model is a multi-regional and multi-period forest sector model that integrates forestry, forest industries, final demand for forest industry products and international trade in the products. The model includes 61 regions covering the whole world, but the regional disaggregation is most detailed in Europe, with most European countries modelled as individual regions. The version used in this study encompassed about 30 forest industry and energy sector products, 5 round wood categories, 3 categories for forest chips, 4 recycled paper grades, and the side products of the forest industries. In principle, the model can be run for any number of periods, but due to the large uncertainties in the longer term, the usual time horizon covered by the model analyses is up to 20 years ahead.

The methodology of the model is based on the partial equilibrium approach, where the existence of the other sectors of the economy is only indirectly taken into account. The model looks for the competitive market equilibrium for all products and regions. This includes

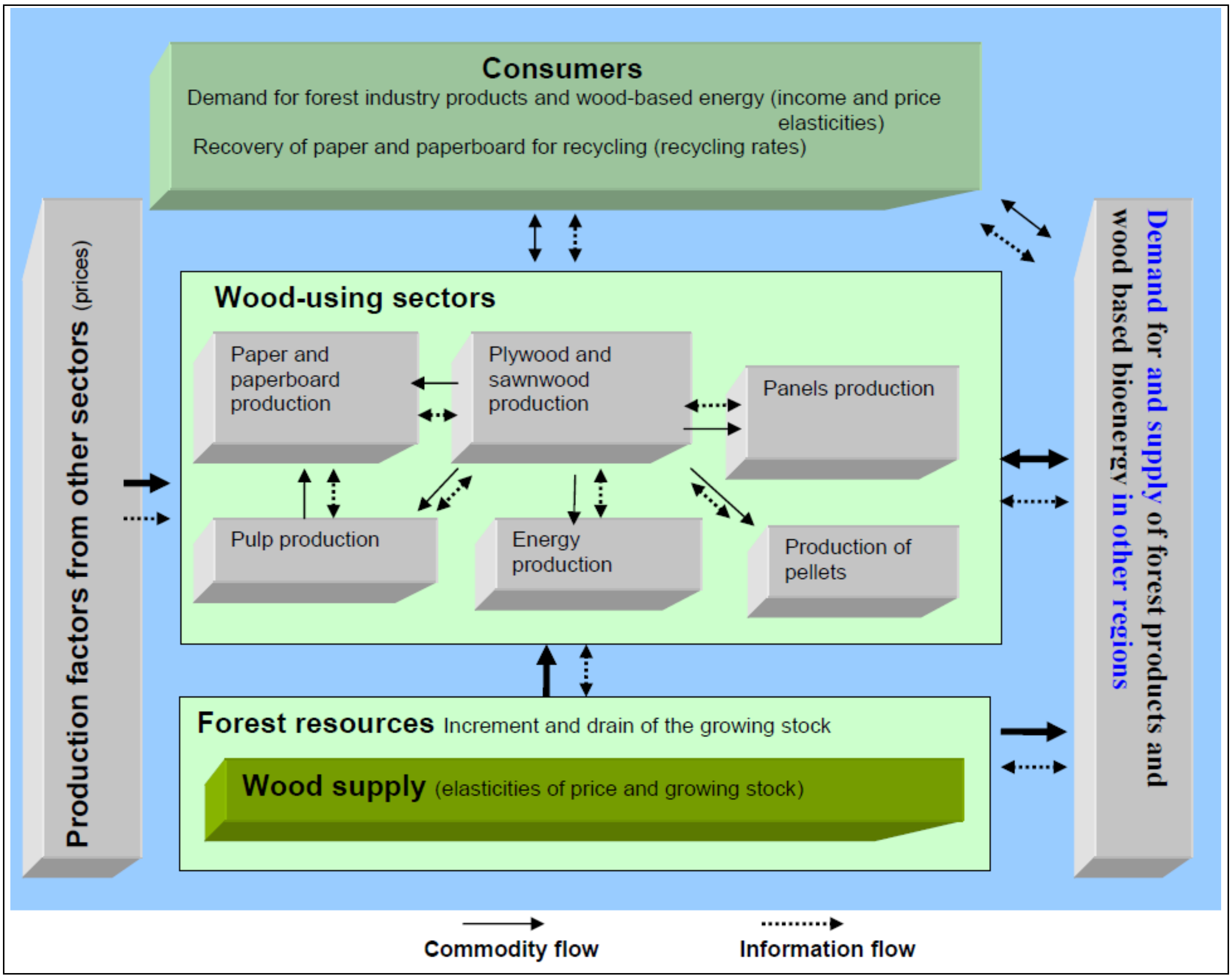

Figure 1. Simplified model structure of EFI-GTM for each region.

production quantities, prices and trade for all products and regions included in the model for each period, which the analysis covers. The market equilibrium is solved by maximizing the sum of consumers' and producers' surpluses of all regions and products minus the trading costs. The model is solved in a recursive-dynamic fashion by one period at a time, updating the relevant data for the next periods in each step.

Technological change can be addressed in different ways in the model. First, in the initial year, the production capacity is divided into three or more alternative technologies. Second, for each product, one can exogenously specify the speed of technological improvement, giving a corresponding decrease of production costs or use of inputs. Third, the most modern low cost technologies will typically be chosen for the new investments. In this study, we assumed that labour costs are assumed constant over time, thus indirectly assuming that even when input of labour measured in hours per unit of production may decrease through introduction of labour-saving technologies, the salaries will increase to match the so attained productivity increase.

2.2 Energy systems model

In the energy systems analysis of the Best scenarios, the TIMES-VTT energy system model was the core tool. It is a global multi-region model originally developed from the global ETSAP TIAM model (Loulou 2008, Loulou & Labriet 2008). It is based on the IEA TIMES modelling framework (Loulou et al. 2005), and is characterized as a technology-rich, bottom-up type partial equilibrium model. It consists of 17 regions, which are listed in Table 1. The model includes four regions for the Nordic countries (Denmark, Finland, Norway, Sweden), Western Europe, Eastern Europe, CIS (Former Soviet Union excluding the Baltic countries), Africa, the Middle East, India, China, Japan & South Korea, Other Developing Asia, Canada, the USA, Latin America and Australia & New Zealand. For the Nordic regions, the district heat production and demand is divided into four sub-regional areas for better modelling of the heat networks in these countries (Koljonen et al. 2013, Lehtilä et al. 2014).

The representation of energy supply chains starts from the extraction of energy resources, continues through a number of conversion and distribution steps, ultimately leading to end-use to provide a wide variety of energy services in five sectors (industry, residential, transportation, commercial and agriculture). The equilibrium solution is obtained by maximizing the present value of the total consumer and producer surplus over all model regions and periods, assuming perfect competition, employing inter-temporal optimization.

As a partial equilibrium model, the model maintains equilibrium between supply and demand of all commodities, and determines their prices. The final demands of commodities are exogenous only in the Baseline scenario, while in policy scenarios they are elastic to their own prices, according to price elasticities derived from the literature. In policy scenarios, the demands of all commodities are thus affected by their prices, and vice versa.

Table 1. Regions of the global TIMES-VTT model.

Code	Region description
AFR	Africa
AUS	Australia and New Zealand
CAN	Canada
CHI	China (includes Hong Kong, excludes Chinese Taipei)
CIS	Former Soviet Union excluding the Baltic States
EEU	Eastern Europe (excluding CIS)
IND	India
JPN	Japan and South Korea
LAM	Latin America, including Mexico
MEA	Middle-East (includes Turkey)
ODA	Other Developing Asia (includes Chinese Taipei and Pacific islands)
USA	United States
WEU	Western Europe (EU-12 excl. Denmark, Iceland, Malta, Norway, Switzerland)
DNK	Denmark
FIN	Finland
NOR	Norway
SWE	Sweden

The time horizon of the model is flexible, and can be extended to 2100 or even beyond. Here we used a horizon extending to 2065, divided into successive periods of 5–10 years duration, each representing an average year of the period. To reflect seasonal and diurnal variations in supply and demand, each year is divided into five seasons and two daily time segments.

The overall structure of the model in each region is illustrated in Figure 2. Primary bioenergy supply is modelled by using supply-cost curves with 2–7 cost steps for each bioenergy type. For example, the potential of forest residues is modelled with a supply curve of 7 steps in each region, and the potential itself is proportional to the total round wood production. For bioenergy conversion, the model includes a wide selection of technology alternatives.

The model also includes all GHG emissions and sources covered by the Kyoto protocol, and a large number of different emissions abatement options, including fuel switching options, new energy conversion and end-use technologies CCS options.

Furthermore, the TIMES model incorporates also an integrated climate module, with a three-reservoir carbon cycle for CO_2 concentrations and single-box decay models for the atmospheric CH_4 and N_2O concentrations, and the corresponding functions for radiative forcing. Additional forcing induced by other natural and anthropogenic causes, like for instance deforestation, is taken into account by means of exogenous projections. Finally, the changes in mean temperature are simulated for two layers, surface, and deep ocean (Loulou et al. 2010). The climate module is very useful for the analysis of various climate policies,

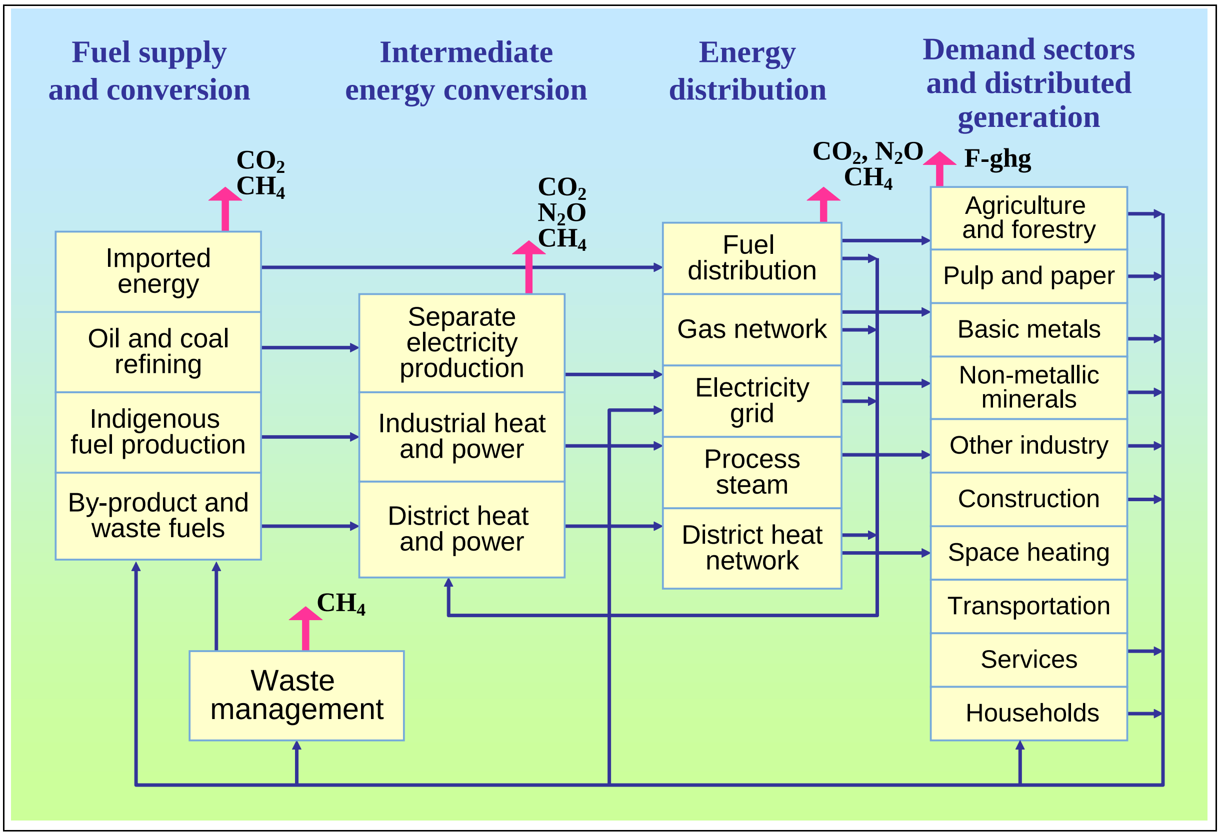

Figure 2. Simplified model structure of TIMES-VTT in each region.

and extends the model into an integrated assessment model.

3 Scenarios

3.1 Overview

Three scenarios were examined, which can be more or less directly associated to three of the six scenarios constructed in the BEST project (Kettunen & Meristö 2014). The scenarios were among the initial four future storylines sketched along the two main dimensions selected: growth in energy demand and growth focusing either on solar or bioenergy.

The scenarios are called “**Crunch**”, corresponding to the fossil strain scenario (“*Bio fossiilisten puristuksessa*”), “**Bio-Inno**”, somewhat loosely corresponding to the centralized bio-policy scenario (“*Keskitetty biopolitiikka*”), and “**Bio-Stor**”, loosely corresponding to the bioenergy storage scenario (“*Biovarasto*”). The main characteristics can be summarized as follows:

- **Crunch**:
    - Energy and climate change policies are not prioritised
    - Solar energy is not subsidized in the short term and therefore technology development is conservative
    - Prices of fossil fuels return to high level
- **Bio-Inno:**
    - Global climate policy ~2°C
    - Price of crude remains below 100 USD/bbl
    - Bioenergy has strong position and is in the focus of European R&D
- **Bio-Stor:**
    - Global climate policy ~2°C
    - Price of crude remains below 100 USD/bbl
    - Solar energy is subsidized in the short term and technology develops rapidly
    - Bioenergy supports other renewables, storage systems evolve

In addition to these three scenarios, a **Baseline** scenario was also calculated for the energy systems analysis as a point of comparison to the three other scenarios. The Baseline scenario assumed only the current EU 2020 energy and climate policies for the Europe, and for the rest of the world no new climate policies were assumed either. The characteristics of the storylines behind the three BEST scenarios are described broadly below and in more details in Sections 4 (population and GDP growth), 5 (energy systems) and 6 (forest sector).

3.2 Crunch

The starting point of the *Crunch* storyline is that the global economic growth is concentrated on the emerging economies, where the growth is faster in consumption than in exports. Yet, the growth is relatively low even there. The development of new technology is also slow. Apart from the EU 2030 policy package, energy and climate policies are not among priorities.

The increase in the demand for energy is therefore relatively high in proportion to GDP growth. The climate change is in the path that leads to 4–5 C degrees global warming.

The climate change impacts of bioenergy use remain controversial. Similar debates continue around the environmental sustainability of shale gas extraction. No global agreements are reached upon these issues. Fossil fuels are used more than ever before and the main reasons for why the non-EU countries might strive for a decrease in their use is their rising prices and the problems of air pollution. The use of biomass does not help to relieve the latter problem, which makes room for nuclear power production to increase strongly both globally and in Finland.

In Finland, bioenergy-related development efforts are focused on energy products from chemical pulp production, and the peat production chain. Otherwise the market players follow the developments in somewhat better growing emerging economies. After Hanhikivi plant still one new nuclear plant will be installed by 2050.

3.3 Bio-Inno

The starting point of the *Bio-Inno* storyline is a moderately good growth in the global economy, where the growth concentrates on the industrialized countries, both the emerging ones and a few older ones. Growth in energy demand is getting further decoupled from economic growth. Global agreements on climate change policies are reached. Solar energy is becoming the leading renewable energy source, even though the pace of technology development and cost reductions slows down. Within Europe, climate change mitigation is a strategic priority for the European Union, and the EU takes a leading role in the efforts towards low-carbon economy, which strengthens its global position.

The EU is able to create uniform standards and targets for the utilization of renewable energy sources, which gives it a position in the forefront of low carbon technologies, especially those related to bioenergy. A unified electricity market is created, covering most of the EU, including the Nordic countries. In the transport sector, diesel oil retains its position in freight transport but in passenger transport electric and hybrid vehicles gain a 20% market share by 2025, with the growth steadily continuing. Also, successful demonstrations of the second generation liquid biofuel plants facilitate their commercial implementation. The supply of bioenergy products becomes more diversified due to new bioenergy concepts, like hybrids with other renewables, while small scale combustion of wood faces regulative challenges.

In Finland, peat production is driven down, and the Hanhikivi nuclear power plant is the only new plant installed after the Olkiluoto 3 plant by 2050.

3.4 Bio-Stor

Like in the *Crunch* storyline, in the *Bio-Stor* storyline the global economic growth concent-rates on the emerging economies, but is higher. International agreements on climate policies are achieved, and they aim at keeping the temperature increase at most about 2°C. Fossil fuel prices increase only moderately, with crude oil prices remaining below 100 USD/bbl.

Solar energy becomes the highest growing energy source, and together with a high penetration of wind power it calls for the development of new energy storage concepts and technologies.

From the global viewpoint, the position of the EU remains stable, but the economic development is uneven within the EU. Total energy demand decreases considerably in the EU due to efficiency improvements, structural changes and carbon leak (i.e. moving industrial production outside the EU). Electric vehicles do not gain a high market share by 2030, as the fuel economy of ICE (i.e. internal combustion engine) vehicle technologies is getting improved through intelligent control systems.

In Finland, economic growth is focused on the present growth-centres. The main drivers for the growth are exports of clean technology and related services. No new nuclear power plants are installed in Finland after the Olkiluoto 3 plant.

4 General background assumptions

4.1 Population growth

On the global level, the population drivers were obtained from the Medium scenario presented in the United Nations population prospects (UN 2011). Although these are already a few years old, they can be still considered quite valid for a long-term scenario analysis. For the Nordic countries, the average of the 2011 and 2013 UN projections was used in order to take into account the latest estimates of immigration into the Nordic region (UN 2013). For Finland, however, the national population projection by Statistics Finland (StatFin 2012) has been used instead, and it ends up in a total population of 5.85 million in 2030 and 6.10 million in 2050. For all regions, the population development was assumed to be the same in all scenarios.

The development of the global population by region is illustrated in Figure 3 and the development in the Nordic countries in Figure 4. According to the projections, the world population will reach about 9.3 milliards by 2050 (UN 2011). The most significant increases occur in Africa, India and Other developing Asia. In particular, the expected expansion of the African population is large, as the population will double between 2015 and 2050.

Unlike in most European countries, the population of the Nordic countries is projected to increase notably in the next decades (Figure 4). This is mainly due to the assumed continuing immigration. By 2050, Denmark, Finland and Norway are all projected to have a population of slightly over 6 million, while the population in Sweden is close to 12 million. The

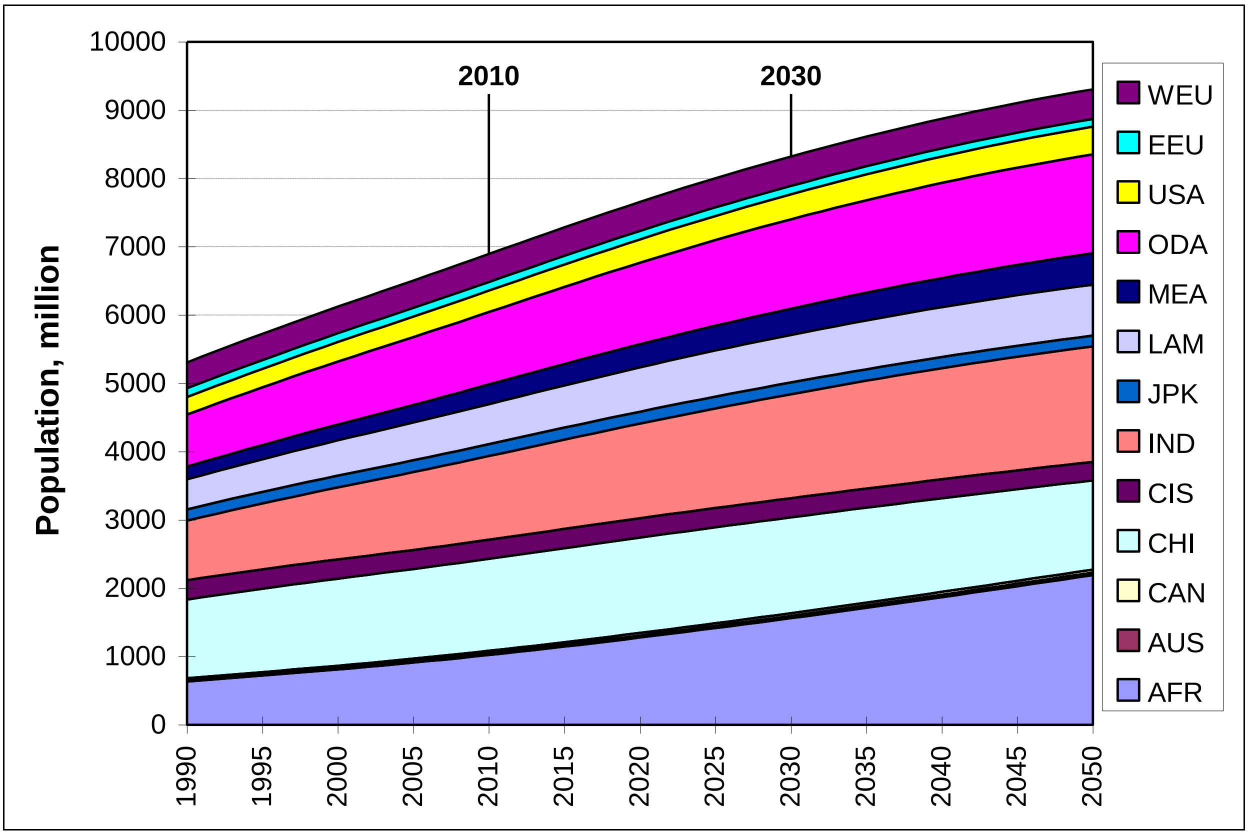

Figure 3. World population development by region (Nordic countries included in WEU).

growth in population is expected to be fastest in Norway, passing Finland around 2040. Finland is expected to have the smallest population among the four countries by 2050.

4.2 GDP growth

We used the OECD's GDP forecast as the Baseline GDP growth in 2020–2050 for most countries (Figure 5). When historic GDP values were needed for preparing the background data, we used the World Bank[1] estimates up to 2012 when available.

For Finland, the Baseline economic growth projections were mostly based on estimates by the Ministry of Employment and the Economy (MEE 2013). As these estimates were available only until 2035, they were extrapolated up to 2050. The Baseline projections for the Finnish economy are illustrated in Figure 6.

Nevertheless, the three Best scenarios were assumed to differ in GDP growth and thereby also in GDP/capita in line with the scenario storylines. The assumed differences in economic growth in the BEST scenarios were applied to both the forest sector model and the energy systems model. For the forest industry production, projections from the EFI-GTM were used the VTT-Times.

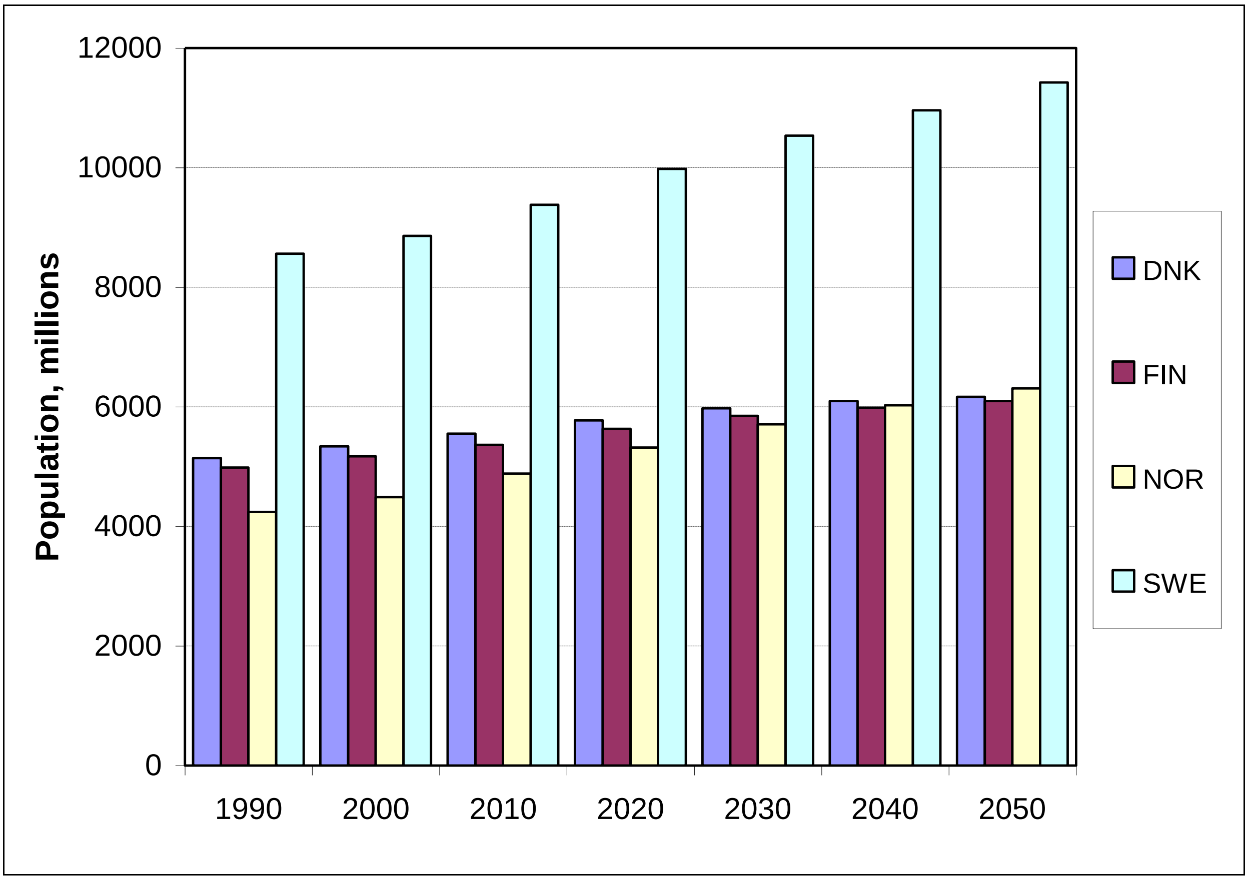

Figure 4. Population development in the Nordic countries.

[1] retrived 2013, http://data.worldbank.org/indicator/NY.GDP.PCAP.KD

In the scenario **Bio-Inno**, the global GDP growth is highest. There, we used the OECD's GDP forecast as a proxy[2] for the GDP growth in 2020–2050 for most countries when available. Nevertheless, during the period 2013–2018, the GDP growth was assumed to develop as forecasted by IMF (2013. In the scenario **Bio-Stor**, the GDP was assumed to grow slower in the developed OECD countries than in **Bio-Inno**, while the economics of rest of the countries were assumed to develop mostly like in **Bio-Inno**. In the scenario **Crunch**, GDP growth was lowered also in the developing countries. Table 2 shows the assumed growth rates for selected countries.

Table 2. Assumed GDP growth in selected countries in the scenarios Crunch, Bio-Inno and Bio-Stor.

	Crunch			**Bio-Inno**			**Bio-Stor**		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Australia	1.20	1.00	1.00	1.69	1.67	1.42	1.20	1.00	1.00
Brazil	2.50	2.30	1.65	2.50	2.55	1.65	3.50	3.50	1.65
Canada	1.20	1.00	1.00	1.36	1.36	1.74	1.20	1.00	1.00
China	6.76	3.88	1.70	6.76	4.31	1.70	6.76	4.31	1.70
Estonia	3.12	1.93	1.35	3.12	2.14	1.35	3.12	2.14	1.35
Finland	1.20	1.00	1.00	1.87	1.31	1.15	1.20	1.00	1.00
Germany	1.20	1.00	1.00	1.30	1.10	1.00	1.20	1.00	1.00
India	7.95	6.51	4.65	7.95	7.23	4.65	7.95	7.23	4.65
Indonesia	5.50	3.74	3.64	5.50	4.16	3.64	5.50	4.16	3.64
Japan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Korea	4.97	3.00	1.00	4.97	3.00	1.00	4.97	3.00	1.00
Norway	1.20	1.00	1.00	2.00	1.00	1.04	1.20	1.00	1.00
Poland	3.70	2.24	1.00	3.70	2.49	1.00	3.70	2.49	1.00
Russia	4.00	3.02	1.27	4.00	3.35	1.27	4.00	3.35	1.27
Sweden	1.20	1.00	1.00	1.59	1.30	1.00	1.20	1.00	1.00
United Kingdom	1.20	1.00	1.00	2.12	2.04	1.64	1.20	1.00	1.00
United States	1.20	1.00	1.00	2.19	2.11	1.58	1.20	1.00	1.00

[2] That forecast was available only for the real PPP income in USD, which was converted back to real USD)

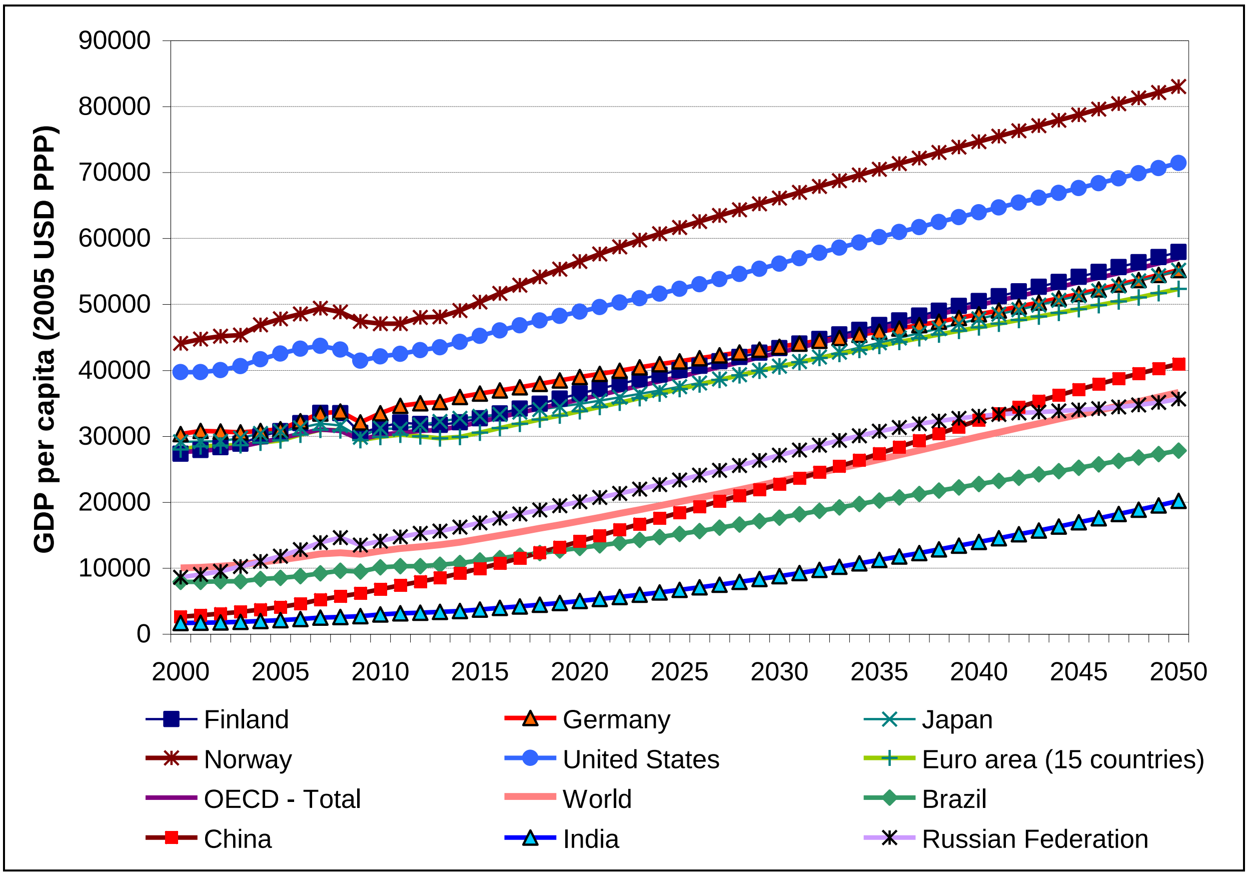

Figure 5. GDP per capita in USD 2005 PPS for selected countries.
(http://stats.oecd.org/Index.aspx?DataSetCode=EO93_LTB#)

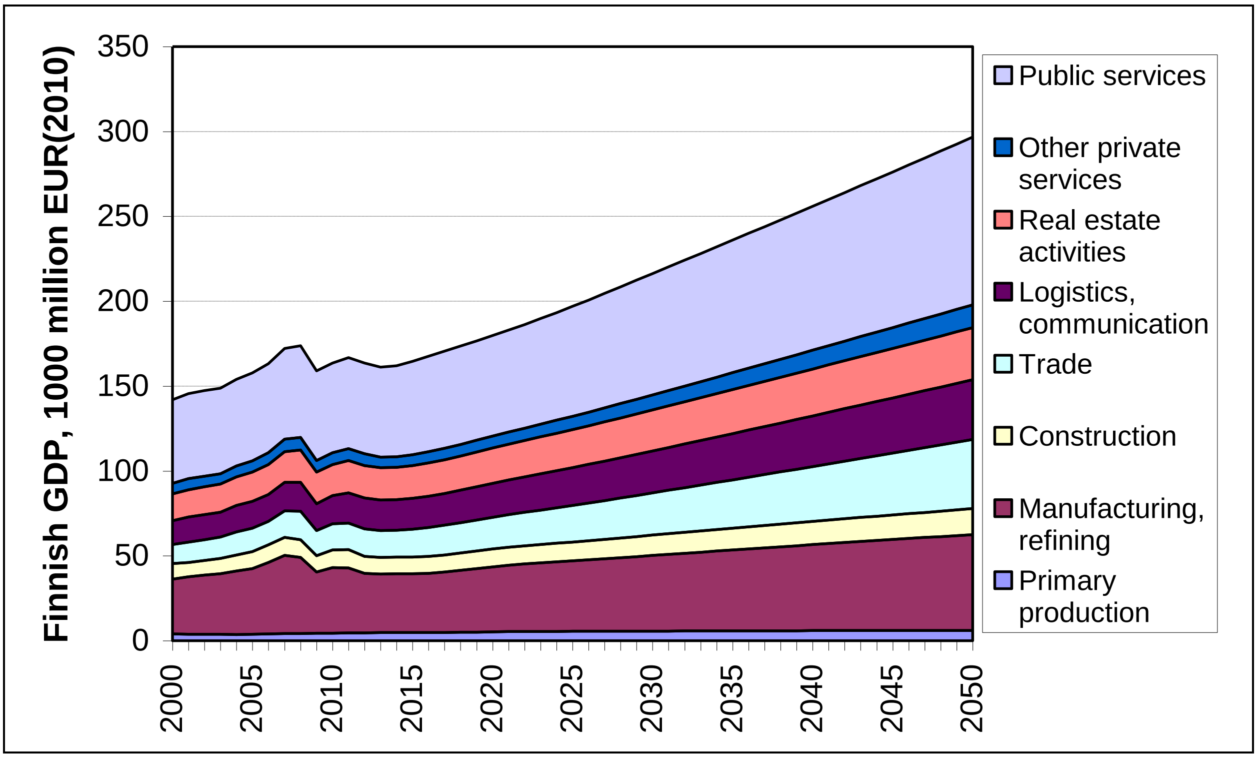

Figure 6. Baseline development of the Finnish GDP until 2050.

5 Background assumptions in the energy systems model

5.1 Overview of scenario assumptions

With respect to the qualitative assumptions in the scenarios, the main differences are summarized in Table 3. Quantifications of the main assumptions are discussed in Chapters 5.2-5.4.

Technology development is relatively rapid in the Bio-Inno and Bio-Stor, but rather slow in the Crunch scenario.

Nuclear power is assumed to retain its competitiveness especially in the Crunch scenario, where the high fossil fuel prices boost investments in nuclear power in the emerging economies. Along with the tight climate policies it is allowed to increase considerably also in the Bio-Inno scenario, provided that it is competitive. However, in the Bio-Stor scenario nuclear power is getting pushed into the background, while renewable energy overtakes the energy technology forefront.

Table 3. Summary of differences in the storylines and the main assumptions used in the scenarios.

Assumption	Baseline	Crunch	Bio-Inno	Bio-Stor
Economic growth	Moderate	Modest, driven by emerging economies	Fair, Finland above European level	Moderate, fair in Finland
Climate policies	EU 20/20 policies	EU 2030-package, regional policies	EU –80% 2050 global ΔT ~2°C	EU –80% 2050 global ΔT ~2°C
Technology development	Conventional	Slowish, Europe follower	Rapid, European biotechnology	Boosted for new renewables & storage
Renewable energy	Current trends	Moderate growth	Rapid growth	Rapid growth
Bioenergy	Current trends	Moderate growth	Strong growth, new business, BECCS	Bioeconomy with new renewables, storage
Nuclear power	Free growth	Large increase, Finland: 2 new	Free increase, Finland: 1 new	Stagnation Finland: no new
Other remarks	–	Biorefinery investment subsidies	Firewood fade-out, CCS commercial, lots of electric cars	CCS is expensive Bio-SNG + LNG

5.2 Bioenergy supply potential estimates

5.2.1 Overview

Historically, the contribution of bioenergy to the global energy supply has been at a relatively stable level. Traditional biomass, mostly firewood, has accounted for most of the bioenergy utilization. Traditional biomass is defined as biomass consumption in the residential and agricultural sector and it refers to the use of wood, charcoal, agricultural residues and animal dung for cooking and heating (IPCC 2012). Most of the traditional biomass is used in developing countries but also the developed countries have traditional use of biomass. All other bioenergy is considered as modern use.

According to IPCC estimates, in 2008 traditional firewood and charcoal still accounted for about 74% of global bioenergy use. Even in Europe firewood still accounts for about 45% of all wood biomass used for energy (see section 5.2.3 below). For example, until recent years, forest residues have been captured to a significant extent only in Scandinavia.

Total primary bioenergy production increased slowly from 31 EJ in 1980 to 54 EJ in 2012. The average annual growth in bioenergy use was only 1.4% between 1980 and 2001, but after that, the growth has become more rapid, such that the average annual growth was 2.3% between 2001 and 2012. However, the growth in total primary energy has continuously remained higher than the growth in bioenergy use, and therefore the share of bioenergy in total primary energy has been decreasing, as illustrated in Figure 7. However, according to many assessments, the growth in bioenergy use could in the future be well exceeding the growth in other primary energy. On the other hand, it is also expected that an increasing

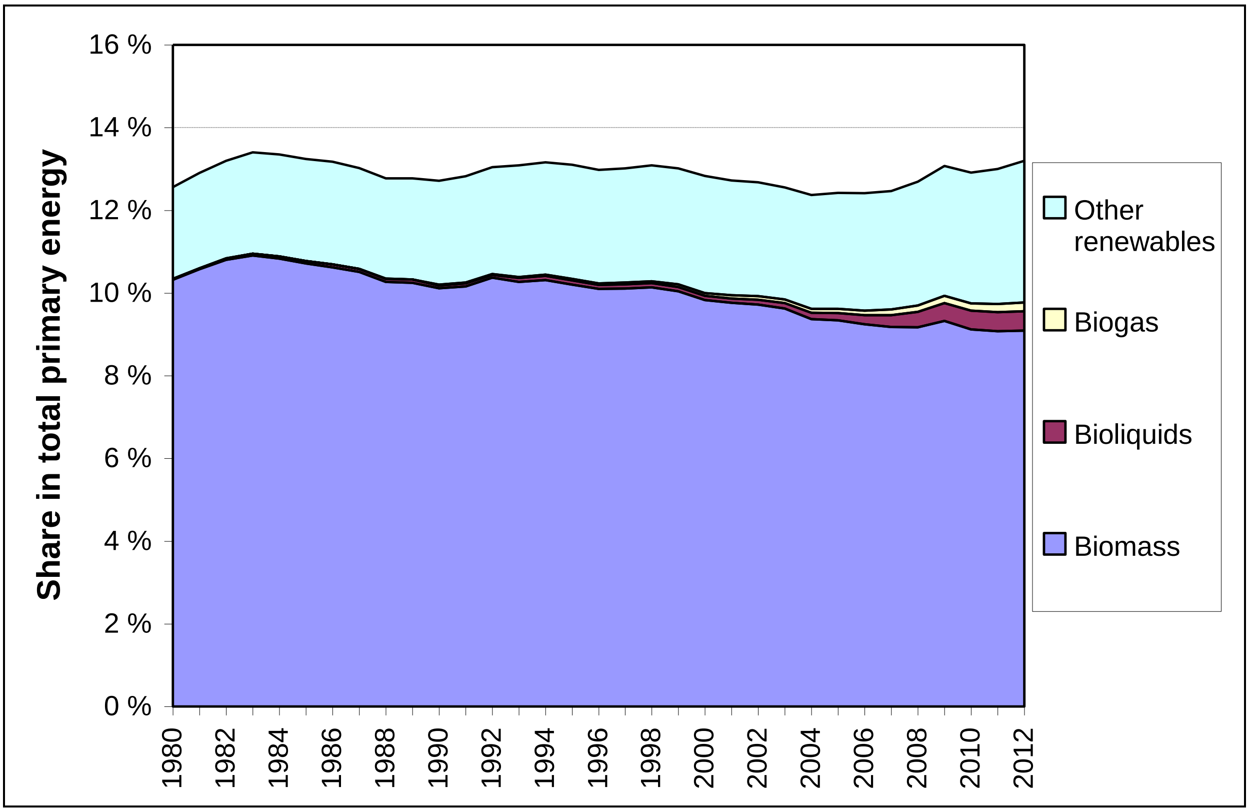

Figure 7. Renewable energy share in global primary energy 1980–2012 (IEA 2014).

share of biomass would be utilized for biomaterials, biochemicals, etc. new products while replacing fossil fuels and other non-renewable raw materials.

Primary bioenergy supply can be divided into the following components:

- Wood biomass
  - Black liquor
  - Other industrial by-product streams from wood
  - Firewood
  - Forest residues
  - Stemwood for energy (usually small pulpwood)
  - Recycled wood
- Agrobiomass
  - Agricultural residues (straw, husk, dung etc.)
  - First generation energy crops (food crops)
  - Second generation energy crops (woody and grassy crops)
- Biogas from agricultural residues
  - From manure or fodder plant streams
- Bioenergy from renewable waste
  - Solid municipal waste, renewable
  - Landfill gas, sludge gas

In the IEA statistics, the production of bioliquids (biodiesel, biogasoline, other liquid biofuels) is also considered primary production, in addition to biogas. This is apparently due to difficulties in collecting reliable data on the energy balances of the refining processes. As shown in Figure 8, the production of liquid biofuels is the fastest growing component in the global bioenergy supply. During 2000–2012, global production of bioliquids increased from

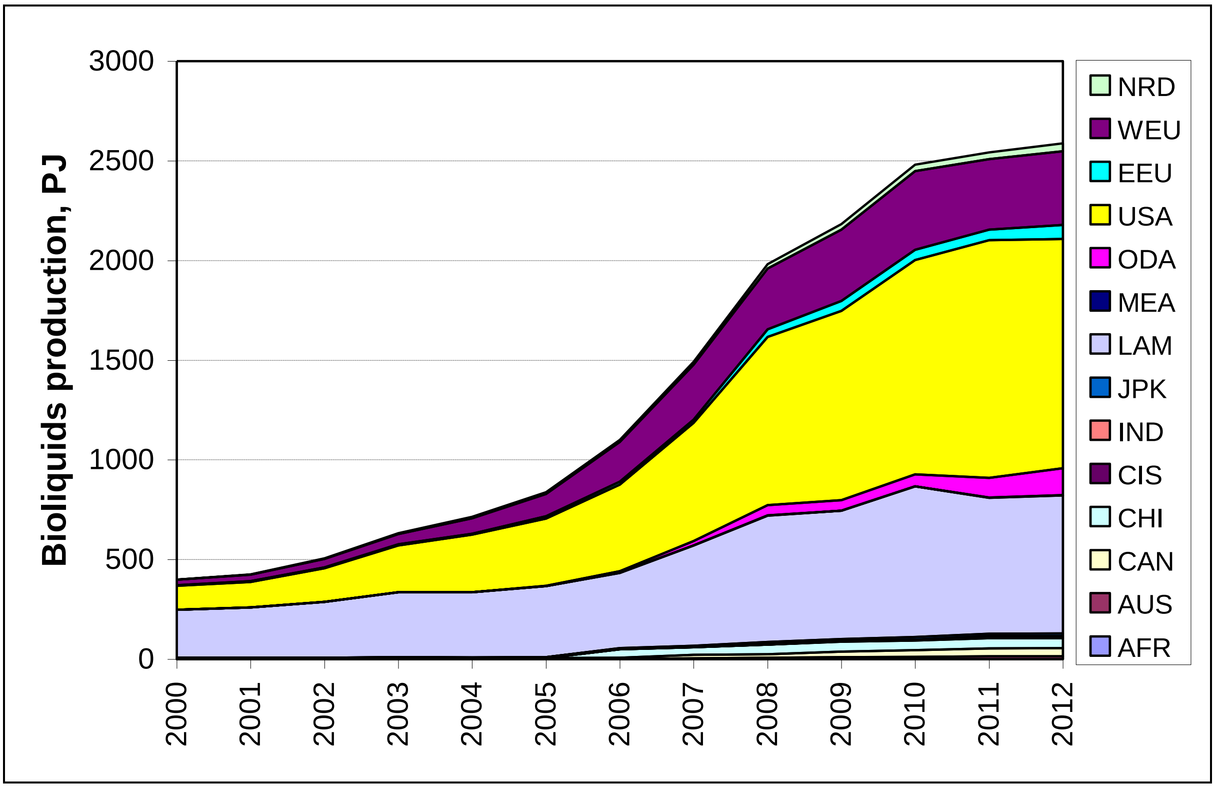

Figure 8. Global production of bioliquids 2000–2012 (IEA 2014).

about 0.4 EJ to 2.6 EJ, i.e. over six-fold. Even though the growth appears to have levelled out in the most recent years, huge increases in biofuels production have been projected by the IEA by 2050 (e.g. IEA 2011).

5.2.2 Global potentials

There are numerous studies on the global and regional bioenergy potentials in the longer term. There is also a wide range in the estimated potentials, both concerning the theoretical potentials and sustainable potentials taking into account the annual growth of forests and competing uses of agricultural land, in particular for food and feed production.

Based on a study by Krewitt et al. (2009), the IPCC Special Report on Renewable Energy (SRREN), gives a base estimate for global total bioenergy potential amounting to 129 EJ in 2030 and 184 EJ in 2050, using strong sustainability criteria. The range of low and high estimates is also given, and is between 50 and 500 EJ (IPCC 2012). However, the base estimates do not seem to include all traditional biomass, as they cover only residues and crops, and the low estimate for residues is only 32 EJ in 2050, which is much lower than the total biomass use today. The full base estimate for the total sustainable potential should thus apparently be somewhat larger than the 184 EJ in 2050 mentioned above.

At VTT, data on regional bioenergy potentials have been obtained both from various international sources, as well as from earlier studies carried out by MTT (Hakala et al. 2009, Pahkala & Lötjönen 2012). With all these estimates put together, the total bioenergy potential assumed in the TIMES-VTT model for the Best scenarios is as shown in Figure 9. As one can see, the total potential is in good agreement with the SRREN base estimates for both 2030 and 2050, insofar as that traditional biomass was indeed not fully included in the IPCC estimate. For 2030, the total potential is about 140 EJ, and for 2050, about 195 EJ. As clearly seen from the figure, energy crops (including short rotation forestry) have the largest future

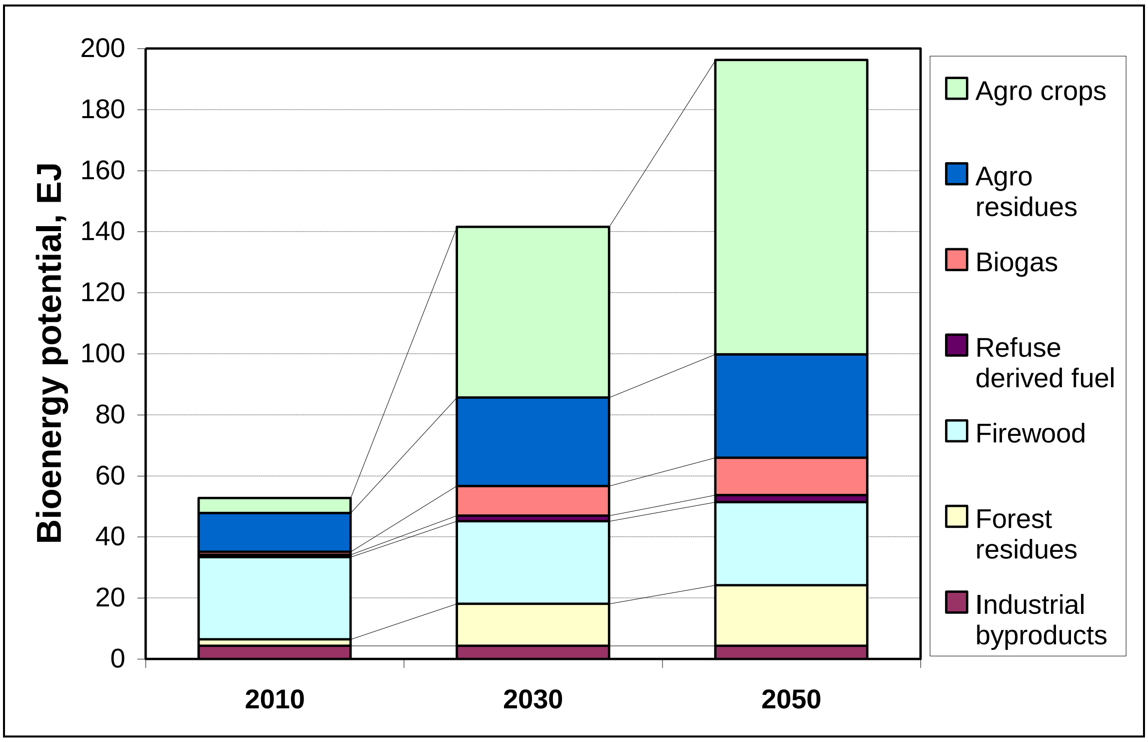

Figure 9. Assumed bioenergy potentials on the global level.

potential. In the TIMES-VTT, forest biomass potential estimates are mainly based on an EFI study for Europe (Asikainen et al. 2008), and on a study by Smeets & Faaij for other regions (2009). The global wood biomass potential is about 45 EJ in 2030 and 50 EJ in 2050. The above potentials could be considered as technical potentials, which take into account sustainability criteria. In the scenario assessments, the model results with EFI-GTM and TIMES-VTT models represent economic potentials for biomass, biofuels and bioenergy.

5.2.3 European potentials

5.2.3.1 Finnish potentials

In Finland, forest biomass is the most important source for bioenergy. In 2010, the total bioenergy use was in Finland about 330 PJ, of which almost 320 PJ was wood-based biomass. The potential for increasing wood bioenergy using domestic forest chips as feedstock is about 100 PJ in the coming decades (Natural Resource Institute, 2015). Forest chips include harvest residues, stumps and small size wood from forest thinning operations.

Agrobiomass potential is relatively small in Finland compared with other European countries. Based on MTT estimates (Pahkala & Lötjönen 2012), we assume that the realizable potential from agricultural residues is about 13 PJ by 2050, and consists mainly of straw. This potential is largely proportional to the agricultural crop production. On the other hand, the bioenergy potential from energy crops is reversely affected by agricultural food crop production. In the TIMES-VTT model, the total use of arable land is modelled according both food and feed and energy crop production, of which the food and feed crops have a priority. Therefore, the potential for energy crops reduces when the production of food crops increases and vice versa.

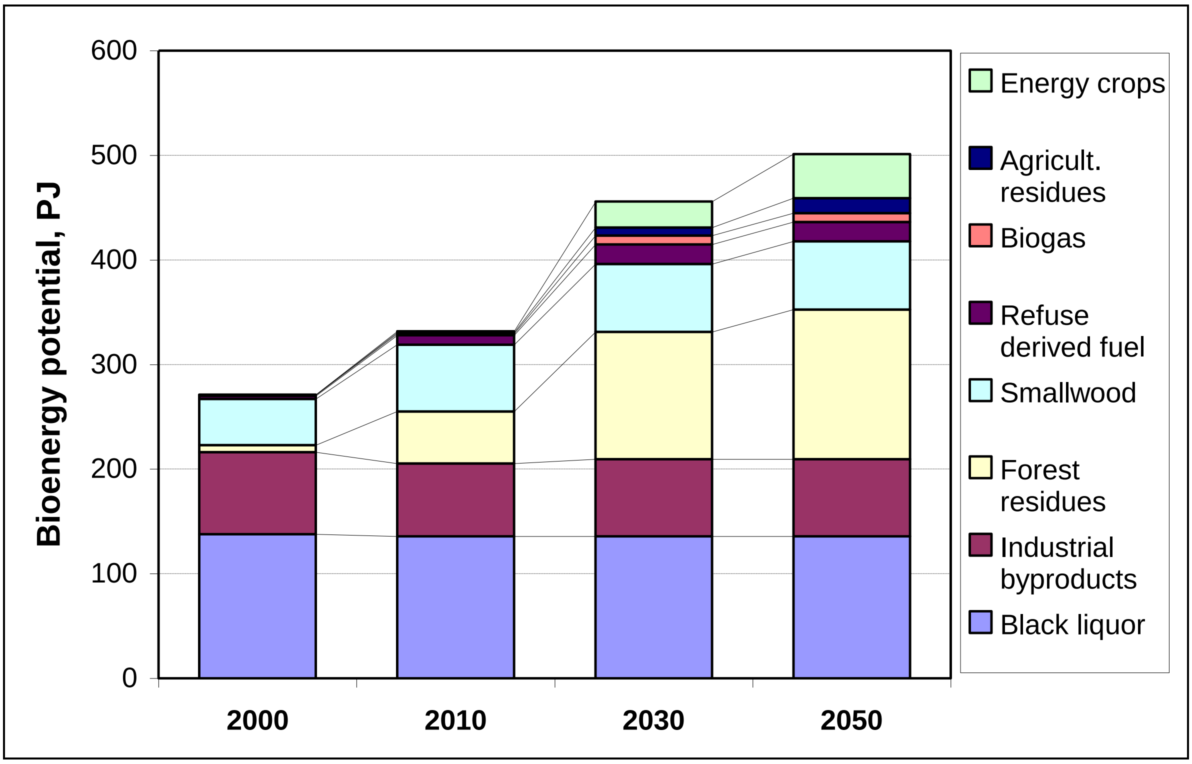

Figure 10. Assumed bioenergy potentials in Finland.

With the baseline projections for the production of food and feed crops in Finland, the energy crop potential is estimated to be 42 EJ by 2050. The total potential for increasing bioenergy use in Finland is about 125 PJ by 2030 and about 170 PJ by 2050 according to the estimates used in the Best scenarios. However, one might note that biogas potential from fodder by gasification has been very conservatively included in the estimates.

5.2.3.2 Total European potentials

In Europe as a whole, bioenergy is still in a rather minor role in the energy supply. In 2010, it accounted only for about 5% of the total primary energy supply, of which wood biomass was about two thirds. The total European production was about 5.1 EJ in 2010.

There is a very wide variation in the estimates concerning the future bioenergy potential for Europe. In the survey by Bentsen and Felby (2012), the range in various energy crop potential estimates was found to be 4.3–6 EJ for 2030 and 3–56 EJ in 2050. In the Best scenarios, the estimates adopted for VTT-TIMES model are based on studies by Asikainen et al. (2008) for forest biomass, on Hakala et al. (2009) for agricultural residues, and mostly on de Wit and Faaij (2010) for energy crops. According to these projections, energy crops dominate the potential for increasing bioenergy use, as shown in Figure 11. However, there is also a notable potential for increasing the utilization of forest residues for energy, which until recently has been done on a wide-scale only in Finland and Sweden.

By 2030, the total biomass potential is estimated to be about 14 EJ by 2030, which is almost three times as much as the supply in 2010, but 90% of the additional potential is related to agrobiomass and biogas. Energy crop potential would be about 5.4 EJ in 2030 and 9.9 EJ in 2050, and the potential from agricultural residues about 2.6 EJ in 2030 and 3.2 EJ in 2050. Even though the potential increase appears quite remarkable, until 2020 the trends appears

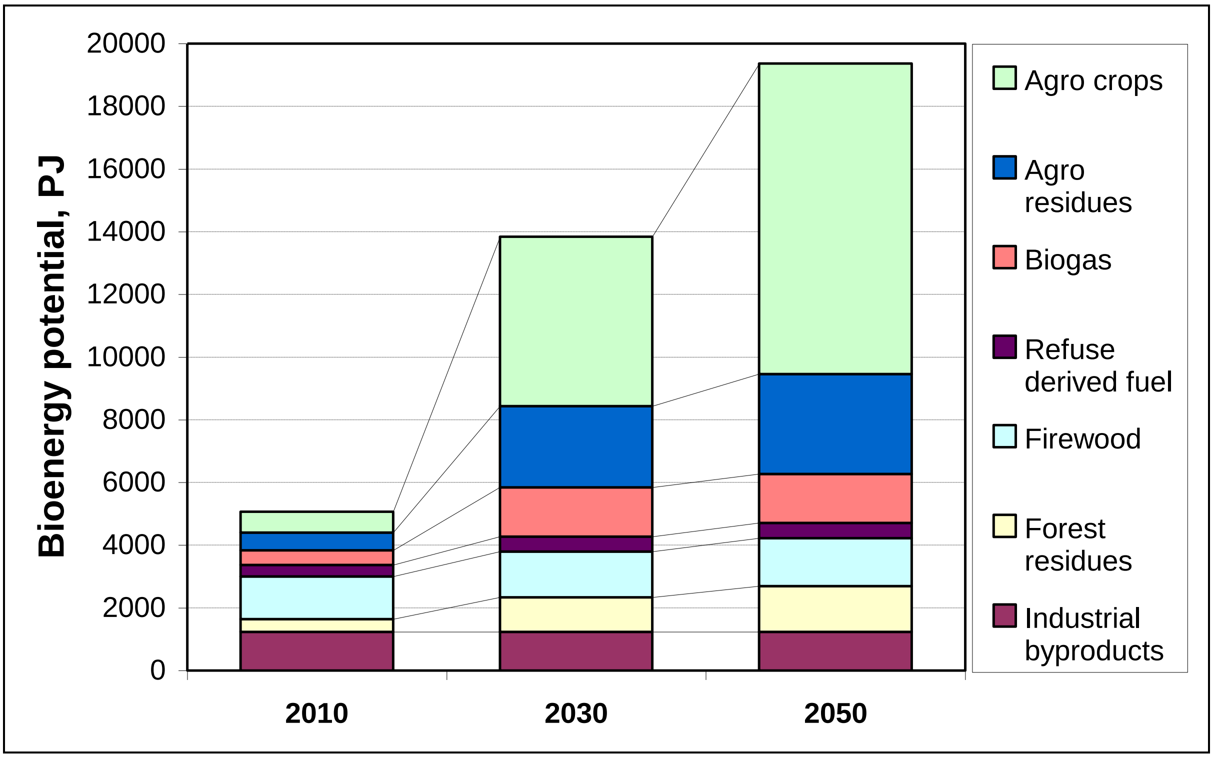

Figure 11. Assumed bioenergy potentials in the European level.

to be in a relatively good agreement with the estimated demand for biomass for energy in the EU27 countries based on national renewable energy projections, totalling in about 10 EJ already in 2020 (Bentsen & Felby 2012).

5.2.4 Uncertainties in the potential estimates

As agricultural bioenergy production is likely to play a major role in the future, it is important to bear in mind that its sustainable production is strongly tied to the available surplus land and food and feed crop production. The development of human diets may thus have a strong effect on the total bioenergy potential. Figure 12 illustrates the variation of the crop potentials from croplands and grazing lands in 2050 according to one study, showing the geometric mean of all 'feasible' and 'probably feasible' scenarios plus the minimum and maximum level of all scenarios within each assumption on diet. The range of the potentials (from cropland and grazing land, 58–161 EJ) is considerably lower than according to many other studies, but gives a good idea of the uncertainties introduced by diets (Erb et al. 2009). In particular, the potentially changing diets in developing countries, where the diets have been until now mostly vegetarian, may have a strong decreasing impact on the crop potentials.

Major uncertainties are also related to climate change. The impact of global warming on biomass yields per hectare varies strongly by region, and can be positive in some regions while quite negative in many others. On the global scale, it is estimated that the impacts of climate change on yields are negative, unless the CO_2 fertilization effect is not taken into

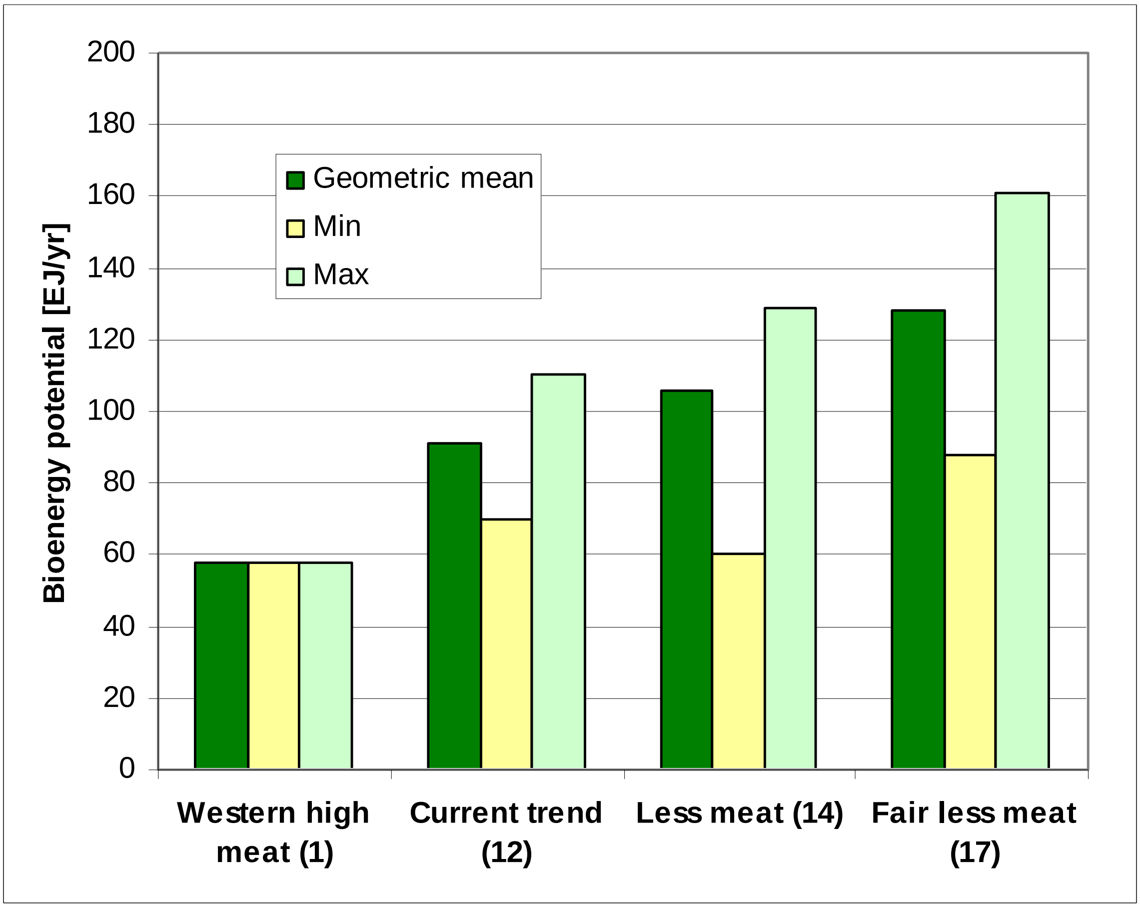

Figure 12. Impact of assumed diets on the energy crop potential (numbers in brackets are the number for 'probably feasible' scenarios for each diet, see Erb et al. 2009).

account. However, if the fertilization effect is taken into account, the global impacts could be even strongly positive (Erb et al. 2009). As yet, the magnitude of the effect has not been reliably assessed under real-world conditions.

In addition to the above uncertainties it could also be expected that there will be increasing demand of biomass for material use and bio-chemicals. The cascading principles along with the promotion of the circular economy might have an impact on biomass energy use in the long term as well. These aspects have only partly considered in the Best scenarios (i.e. linked to the alternative scenarios for forest industries and demands of forest products).

5.3 Technology projections

5.3.1 Bioenergy technologies

The economic potential of increasing bioenergy use is dependent on the competitiveness of biofuels and other bioenergy raw materials with respect to other energy sources. Climate, energy, industrial, agricultural, environmental, etc. policies can therefore have a large impact on the economic potential. In particular, bioenergy has a large potential in the decarbonisation of transportation by replacing fossil fuels with liquid and gaseous biofuels. According to the IEA 2011 roadmap, liquid biofuels could provide 27% of global transportation fuel consumption by 2050 mainly by replacing diesel, kerosene and jet fuel (IEA 2011).

In the Best scenarios, 2nd generation bio-refineries were therefore one of the key bioenergy technologies to be considered. The model includes about 20 technologies for liquid and gaseous biofuels production in each region, for which the technical and economic data has

Table 4. CCS: carbon capture and storage, SNG: synthetic natural gas.

Technology	Feedstock(s)	Available	Investment cost (2030) €/kW(out)	Tech-nical life	Fuel output / feedstock (2030)
Biodiesel, integrated	wood	2020	2627	25	95 %
Biodiesel, integrated	black liquor	2030	2770	25	95 %
Biodiesel, non-integrated	wood, 2nd gen. crops	2020	2145	25	57 %
Biodiesel, non-integrated, CCS	wood, 2nd gen. crops	2030	2482	25	51 %
Biodiesel, non-integrated, CCS	black liquor	2030	3200	25	92 %
Biogasoline, non-integrated	wood, 2nd gen. crops	2030	2459	25	57 %
Biogasoline, non-integrated, CCS	wood, 2nd gen. crops	2030	2803	25	50 %
SNG, non-integrated	wood	2020	1682	25	72 %
SNG, non-integrated, CCS	wood	2030	1983	25	72 %
Heavy bio-oil, integrated	wood	2010	660	25	78 %
Ethanol	1st gen. crops	2010	1060	25	56 %
Ethanol, ligno-cellul.	residues, 2nd gen crops	2020	1990	25	42 %

been collected from literature (e.g. Hannula & Kurkela 2013, McKeogh & Kurkela 2008, Kakkonen & Syri 2014). The base estimates for the investment costs and feedstock efficiency in 2030 are shown in Table 4 for the key technologies. By-product flows and ancillary energy inputs were also taken into account for the processes. The base estimates were mostly used for both the Bio-Inno and Bio-Stor scenarios, however, the CO_2 transportation and storage costs were assumed higher in the Bio-Stor scenario. In the Crunch scenario (and Baseline), the CCS options were excluded, and the investment costs of the bio-refineries were assumed higher. However, in Finland investment subsidies or other support for 2nd generation bio-refineries were assumed to be available in the Crunch scenario. In practice the EU 2030 policy package would essentially result in higher penetration of 2nd generation liquid biofuels because of the tightening GHG reduction targets of those sectors excluded from the EU's emissions trading sector (i.e. non-ETS), like transport. The advantage of 2nd generation biofuels is that they could be used 100% in the existing vehicles, unlike 1st generation biofuels. However, it should be noted that modelling and analysis of the transport sector is a very challenging task due to several technological options for future mobility and uncertainties related to costs and policies.

Power and heat generation is another important sector where the potential for increasing bioenergy use is quite large. The TIMES-VTT energy system model includes a considerable number of different bioenergy-based technology options for both combined heat and power production (CHP) and condensing power. Integrated gasification combined-cycle technologies may become particularly attractive in CHP applications due to the very high power-to-heat ratios reached. Other important technology options for biomass included in the model are co-firing options, oxyfuel CFB combustion (i.e. circulating fluidized bed combustion) technology, and solid oxide fuel cells with integrated gasification.

In addition, for the Bio-Inno and Bio-Stor scenarios, low temperature district heating networks were considered, together with an additional set of CHP technology options that take advantage of the low heat temperatures and achieve better power-to-heat ratios. However, first investments into these technologies were assumed to start around 2025 at the earliest, so their impact on the 2030 energy system will inevitably remain quite small in the results.

5.3.2 Other renewable energy technologies

After bioenergy, **hydro power** (or falling water) is globally the second most important renewable energy source. According to the IEA, hydro power accounted about 2.4% of the global primary energy supply in 2012, while bioenergy accounted for 9.8%. Globally, there is still considerable potential for increasing hydro power production. According to the IPCC SRREN, the global technical potential for hydro power generation is about 14.5 PWh, while the generation in 2012 was 3.6 PWh (16.2% of all electricity). In the TIMES-VTT model, somewhat more conservative realizable potentials have been used, based on World Energy Council (WEC) estimates (WEC 2007), and totalling in about 8.2 PWh in 2050. In Finland the additional hydro potential is assumed to be relatively small, according to a survey made in 2008 (Vesirakentaja 2008). Hydro power technologies are mature, with no major breakthroughs expected in the scenarios. The assumed capital costs for new hydro power plants of different types were based on international data published by ETSAP (ETSAP 2010).

Wind power generation has been rapidly expanding during the 2000s. However, its share of global total electricity generation was still only 2.3% in 2012. In many regions, there is potential to increase the share of wind power even to 30–50% by 2050, but such high shares would require notable investments into power system reserves, regulating power, and infrastructure. In the model, both wind power potentials and technologies have been divided into 10 classes, representing different wind conditions for onshore, near-shore and offshore plants. All potential and cost estimates are based on estimates made by the VTT's wind power experts. Most optimistic estimates for the evolution of investment costs were used in the *Bio-Stor* scenario.

Solar energy is expected to become the key renewable energy source in the Bio-Inno and especially in the Bio-Stor scenario. In the Baseline and Cruch scenarios, the full investment costs of new PV installations (i.e. including the whole PV system) were assumed to decrease to about 550 €/kW by 2050, whereas in the Bio-Stor scenario a considerably more optimistic assumption was made with these costs decreasing to about 250 €/kW. In the Bio-Inno scenario, the capital costs were assumed to reach the level of 400 €/kW by 2050. The maximum solar PV potential in Finland was calibrated at about 20 TWh (based on Solpros, 2001).

Energy storage technologies will become increasingly important if the share of variable electricity generation (solar, wind, run-off river hydro) becomes prominent in the overall supply. Today, pumped hydro is the most widely used storage technology, but in the future other technologies, such as compressed air storage (CAES), super-capacitors, advanced batteries or superconducting magnetic storage (SMES), are also expected to become competitive. In the Bio-Stor scenario, we assumed the cost of large-scale electricity storage to decrease to the level of 500 USD/kW (ETSAP 2012), thereby providing an option for achieving added system flexibility under large penetration of variable renewable generation.

5.3.3 Nuclear power

Nuclear power provides an alternative form of carbon-free electricity generation, which due to its firmness may provide an important contribution to the electricity supply together with the expanding variable generation from renewable energy sources. In the Crunch scenario, global nuclear power generation is assumed to roughly double by 2035, mainly due to the emerging economies investing into it as a reaction to the high fossil fuel prices. In the Bio-Inno scenario, investments into new nuclear power were more freely left to the model to decide, under the same upper bounds as in the Crunch scenario. In the Bio-Stor scenario, nuclear power generation was not allowed to exceed the 2010 level in any region, except Finland.

In Finland, the assumptions concerning nuclear power were set along the same lines. In the in the Crunch scenario, we assume that two new plants would be built after Olkiluoto 3 plant during the 2030s, in the Bio-Inno scenario only one new plant is assumed, and in the Bio-Stor scenario no new nuclear power plants are built. In the Bio-Stor case, this means that in 2050 only the Olkiluoto 3 plant would remain in operation, as illustrated in Figure 13. However, it should be noted that the scenario modelling was completed before the negative decisions on the Olkiluoto 4 plant in the fall 2015. As a result, the nuclear assumptions of the baseline scenario are too high compared with the current situation. In addition, in the Crunch scenario, the nuclear assumptions might also be too optimistic.

5.4 Assumptions on climate policies

In the energy system analysis, we considered all the six greenhouse gases of the Kyoto protocol CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), as well as HCFs, PCFs and SF_6 (F-gases). The climate policies modelled in the scenarios thus always involve the total emissions of all these six greenhouse gases.

For Finland, the following assumptions were used concerning the energy and climate policy:

- Current policies related to the EU 2020 policy targets were assumed to be in force in all scenarios.
- Current energy and carbon taxes as well as subsidies were assumed to remain in force indefinitely, except for the feed-in tariffs, which were not taken into account.
- Instead of the feed-in tariffs for renewable energy, the corresponding targets behind

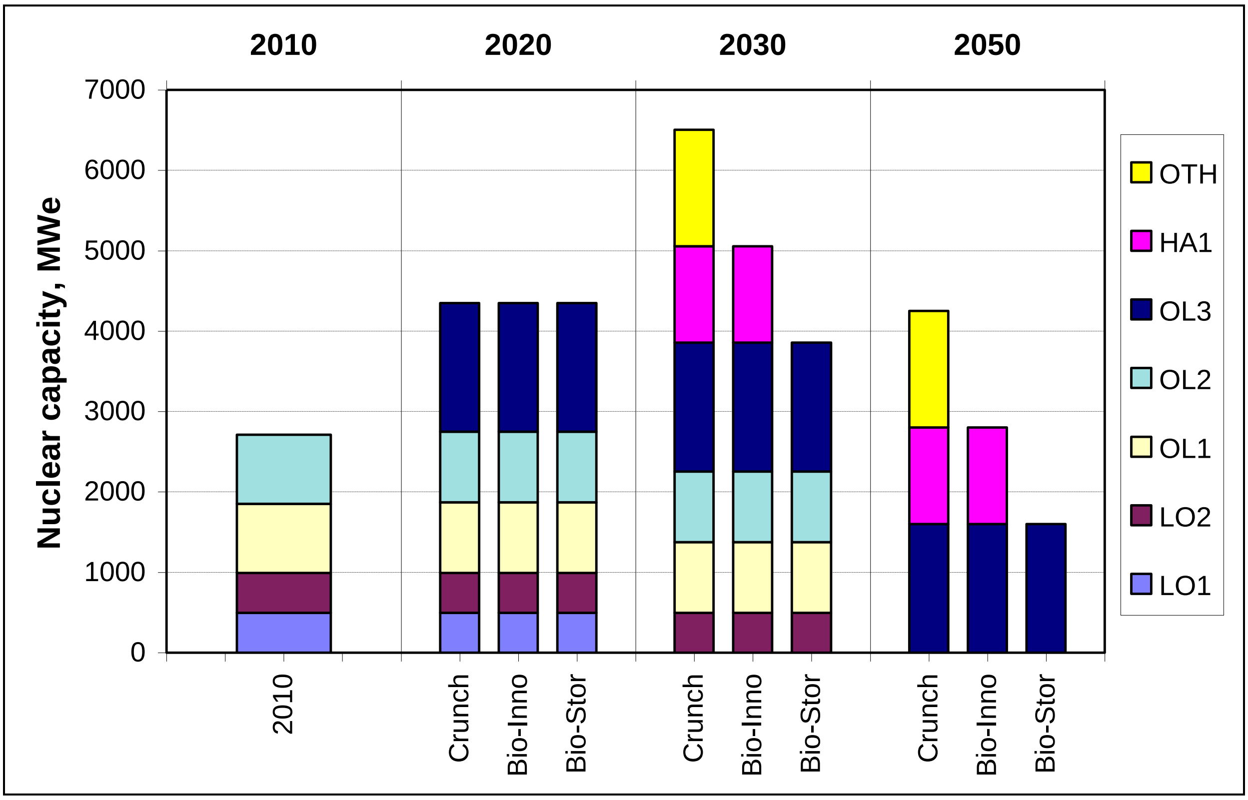

Figure 13. Assumed development of nuclear power capacity in Finland.

them were simulated by defining minimum levels for the renewable energy sources (e.g. wind power and forest residues).

- In the Crunch scenario, the Emissions Allowance prices of the EU ETS system (i.e. EUA) were exogenously assumed to increase according to the Reference scenario published by the European Commission (EU 2013) until 2030, where after they were assumed to remain constant at the 2030 level. In the Bio-Inno and Bio-Stor scenarios, the EUA prices were endogenous (determined by the constraint trajectory for the total GHG emissions).

Most of these assumptions were applied as such also to the other European regions, but energy and carbon taxes were comprehensively modelled only for the Nordic countries.

For the global policies in the Bio-Inno and Bio-Stor scenarios, the target of limiting the temperature increase to at most about ~2°C was expressed by setting an upper bound on the total radiative forcing from all greenhouse gas concentrations. The bound was estimated at 3.2 W/m^2, in line with the median estimates by Meinshausen et al. (2009). One should note that this level of forcing is somewhat higher than usually assumed in climate policy scenarios with the 2°C target (2.6–2.9 W/m^2), and is therefore slightly less ambitious. In the Crunch scenario, only regional emission targets were assumed, corresponding to the EU 2030 climate and energy policy package for the EU, and roughly to the long-term pledges presented by other countries for the rest of the world.

In the Bio-Inno and Bio-Stor scenarios, separate GHG emission reduction targets were also assumed for the European Union, in addition to the global target on radiative forcing. The targets were set for 2030, 2050, and intermediate years, and were expressed in terms of the total CO_2 equivalent GHG emissions, excluding those from marine bunkers. The EU-level reduction target was 40% for 2030 and 80% for 2050 (see Table 3).

5.5 Production of forest industries

For the energy systems analysis, the projections for the production of forest industry products were taken directly from the EFI-GTM model results, which are presented in more detail in Sections 6 (background assumptions) and 8 (results).

6 Some assumptions made on forest sector development

6.1 Forest product demand

The assumptions on the demand for final forest products are essential for projecting the forest industry development in the world. In the EFI-GTM model, the demand is depicted as follows. For each product, region, and point of time, we define a demand function for final products (like newsprint, sawn wood, dissolving pulp) which is downward sloping with respect to price. These functions are parameterized so that the observed market price (reference price) equals the observed demand (reference demand) in the base year 2010. The future reference demand levels may be higher or lower than that in the base year depending on the assumptions made, but the price at the point of such new reference demand is assumed to be the same as in the base year. Hence, it is assumed that, in later years, more or less is consumed at the current price due to changes in market size. Nevertheless, actual demands are not fixed to these reference levels, but they can be lower or higher depending on the product price determined in the market. For a demand level higher than the reference demand, price is lower than the reference price and vice versa. Table 5 summarizes the assumed reference demands for forest products over the time in the global level.

For specifying the magnitude for a change in demand when price goes up or down, non-positive price elasticity is defined for each product. The price elasticity can be interpreted as being a measure predicting by how many percentages the demand changes when price changes by 1%. The forest products have typically rather inelastic demand with respect to price, and price elasticities have typically been estimated to be of the order of -0.15 – -0.2 and seldom below -0.5. This means that in order for producers to gain even slightly higher sales volumes in the market, the prices must decrease considerably. On the other hand, if the supply side is tight to satisfy the increased market demand due to e.g., shortage of the production capacity, the price can increase considerably. This phenomenon has been seen in strong price fluctuations in the past decades.

The eventual market consumption levels taking place in the scenario projections are market equilibrium outcomes of the model simulations and they can be lower or higher than the reference demands in Table 5. This is because they also depend on the suppliers' production choices which are affected by the market price of the output, production costs and available production capacity. The eventual market price equilibrates the demand to supply.

6.1.1 Mechanical forest industry products

Hänninen et al. (2014) anticipate only weak growth for housing demand in Europe in the near decades owing to the projected sluggish economic growth and the fact that the number of inhabitants in Europe is projected to stagnate while the population is rapidly ageing and urbanizing towards 2030. Considering these demographic and socio-economic trends, the consumers' preferences over different construction materials can play a more important role in determining the long-term prospect for sawn wood demand in the European market than the growth rate of economy. The change in the use of wood in the long run can be depicted by a change in the consumption per capita. In the scenario definitions Crunch and Bio-inno, we follow these lines of thought for Europe and extend them to the rest of the world and other wood products than sawn wood as well.

Table 5. Assumed reference demands in the scenarios in selected years. World totals.

	Crunch			Bio-Inno			Bio-Stor		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Softwood sawn wood	284.8	296.4	307.8	300.7	350.8	461.1	310	336.8	384.9
Hardwood sawn wood	108.3	115.1	124.9	112	129.1	173.7	114.3	133.5	176.4
Plywood and veneer	102.7	106.4	108.1	107.9	125	162.1	131	178.7	272.8
Particle board and OSB	107	109.8	110.8	113.4	131.1	166.2	123.9	157.3	220.5
Other boards	101.4	104.1	102.9	107	123.4	154.4	134.4	197.3	322.3
Mechanical forest industry, Mm³	**704.2**	**731.8**	**754.5**	**741**	**859.4**	**1117.5**	**813.6**	**1003.6**	**1376.9**
Newsprint	20.1	19.4	20.2	20.2	19.4	20.2	20.1	19.4	20.2
Uncoated wood containing	13.2	12.6	12.9	13.3	12.9	13.2	13.2	12.6	13
Coated wood containing	11.7	10	10.3	11.7	10.1	10.4	11.7	10	10.3
Uncoated wood free	43.7	43.6	44.7	43.8	43.6	44.7	43.7	43.6	44.7
Coated wood free	23.2	21.2	21.5	23.2	21.3	21.7	23.2	21.2	21.6
Folding boxboard, WLC and other paperboard for packaging	59.7	67	77.9	61.8	73.7	91	59.7	68.1	79.7
Case materials	165.1	185.5	215.2	170.9	204	250.7	165.1	188.8	220.4
Household and sanitary papers	37.6	45.7	61.9	37.6	46.7	63.7	37.6	46.8	64
Other paper and paperboard	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7
Dissolving pulp and new fibers	7.2	9.7	17.5	9.1	35.1	73.7	8.3	14.8	37.1
Pulp and paper industry, Mt	**413.2**	**446.4**	**513.8**	**423.3**	**498.5**	**621**	**414.3**	**457**	**542.7**

In the Crunch scenario, we assume that the forecasted change in regional populations are the driving force for the demand development of the mechanical forest industry products, while the consumption per capita in each region remains in its 2008–2012 average level.). Depending on the region's population development, this can mean a demand decrease or increase. Yet, this assumption means a high increase in total consumption in the world scale over time (Table 5).

In the scenario Bio-inno, we assume that wood becomes more valued material in construction, furniture and interior design so that the per capita consumption of mechanical forest industry products increases over time. It is assumed that the regional consumptions per capita are 50% higher than their 2008–2012 averages by 2050. However, for softwood sawn wood, we limit the so obtained consumption level to be at most 1.05 m^3 per capita. That was the highest level observed in the world in 2012 (in Estonia, but also Finland gets close to that). The demand increases towards the target level are assumed to take place in the same pace as the assumed changes in real GDP per capita from 2015 to 2050. Hence, the change in per capita consumption is not linear over time. Yet, as in all the scenarios, it remains to be seen how the eventual simulated market demand develops as it can be expected that the producers' costs will increase due to possible regional scarcities in wood biomass.

In the scenario Bio-Stor, we deviate from the above reasoning for forming the demand scenarios and apply the GDP elasticities to the assumed GDP growth. The elasticities were taken from the EFSOS study (Jonsson 2012) but constrained to be in the range of 0.0 – 0.9.

6.1.2 Pulp and new chemical wood fibers

Pulp consumption in the paper and paperboard production drives the demand for chemical pulp. Hence, no separate exogenous assumption is needed on sulfate pulp demand.

For dissolving pulp, fluff pulp and novel pulp grades for various new applications, we made specific assumptions for growing demand development. As the world's population gets wealthier, growing amount of textiles is needed to satisfy the increasing consumption. Dissolving pulp is used to produce viscose and other textile fibers, which can also be used to replace cotton whose production needs ever more scarcer resources, water and land. It has other end-use application as well. Furthermore, diapers for babies and for growing group of elderly people are becoming needed and affordable for more and more people. These and other absorbent materials are made of fluff pulp.

In the Bio-Stor scenario, the growth in demand for dissolving, fluff and other non-paper pulps is assumed to accelerate from 5%/year in 2014 to 6%/year by 2020. After 2030 the growth rate is assumed to decline gradually to 3.5% in 2050. In the Crunch scenario, demand for these pulps increases steadily by 3% over period 2020–2050. In the Bio-Inno, the rate of demand growth is assumed to increase by 1%-point annually reaching 20%/yr in 2031. After that the demand growth is assumed to be 3%/year. See Table 5 for global aggregates.

6.1.3 Paper and paperboard

6.1.3.1 Containerboard

Linerboard and fluting, which can both be made of recycled or virgin fibers (mainly unbleached kraft pulp in case of linerboard and semi-chemical hardwood pulp in case of fluting) are together referred to as containerboard or case materials. During further processing, liner and fluting are joined together to make corrugated board for boxes needed to store and ship both durable and non-durable consumer goods. Hence, the demand for containerboard arises from the demand for these boxes. Although also plastic containers could be used to same purposes, the demand for containerboard is rather inelastic with price elasticity lying between -0.16 – -0.18 (Li & Luo 2010). The income elasticity estimates of the magnitude of 0.4 (Li & Luo 2010, regarding total industrial production in US) have been estimated.

Consumption of containerboard per capita in a country does not correlate well with GDP per capita when examined across the panel of some 50 individual countries included in the EFI-GTM in 2010. While coefficient for such correlation between GDP and consumption per capita is 0.89 for tissue papers and 0.87 for newsprint in 2010, it was only 0.54 for containerboard. One explanation is that GDP per capita as such does not tell how much of the GDP is derived from e.g. production of services instead of manufactured goods. Another explanation is that containerboard is also exported to other countries in the form of corrugated board and cases, which does not show in the apparent consumption statistics for containerboard. Yet, containerboard is bulky and costly to ship for long-distances. The share of the total exports of containerboard produced in the world, 16% in 2007-2012, is indeed the lowest among the main paper and paperboard grades and even lower than that of another bulky product, tissue paper (with exports to production share 21%).

In the scenarios, we assume that the containerboard demand in a country follows the assumed total GDP growth in a country. For that, we apply the GDP elasticity of demand 0.40 for low income countries and 0.3 for high income countries up to 2030. Thereby we assume that the GDP increase in low income countries is more strongly derived from increased production, consumption and shipping of manufactured goods, whereas in the high income countries the emphasis of the GDP growth is in the services. After 2030, we assume that the demand elasticity with respect to GDP starts to decline in all regions so that it is 0.26 and 0.2 in high and low income countries, respectively (2% annual decline). Here, we assume some saturation in the material consumption needs of the people. Yet, the overall demand is growing (Table 5).

6.1.3.2 Cartonboard

Cartonboard includes grades like folding boxboard, white line chipboard, liquid packaging board and other board used for packing food, cosmetics, medicines and consumer products. For these products, we let the reference demand follow the assumed total GDP growth like in the case of containerboard above. There are no recent income elasticity estimates for cartonboard available, perhaps due to the large heterogeneity of the product group and lacking statistics.

For the demand growth projections in the BEST scenarios, we chose to apply the same GDP elasticities than those for containerboard, i.e., 0.3 for high income countries and 0.4 for low income countries, with a 2% annual decline in the elasticity applied after 2030. The sum of the so derived reference consumption levels in the different scenarios can be seen in Table 5.

6.1.3.3 Household and sanitary papers

Household and sanitary papers from a product group with growing market demand. We assume that the consumption of tissue papers depends strongly on the income of the households proxied by the GDP per capita. We estimated a function between tissue paper consumption and GDP per capita in 2010 (Figure 14) and used that as a tool to make assumptions on future consumption levels. If per capita consumption was initially above the level suggested by the function, we let it stay there until the increasing income would move it to the next level. If per capita consumption was below the value suggested by the estimated function, we let it to remain there in the future as well, but increased it, respectively, in pace of the income development. If the demand was above the function, we increased it annually at most by 0.5%. Table 5 summarizes the assumed reference demand growth in the world level.

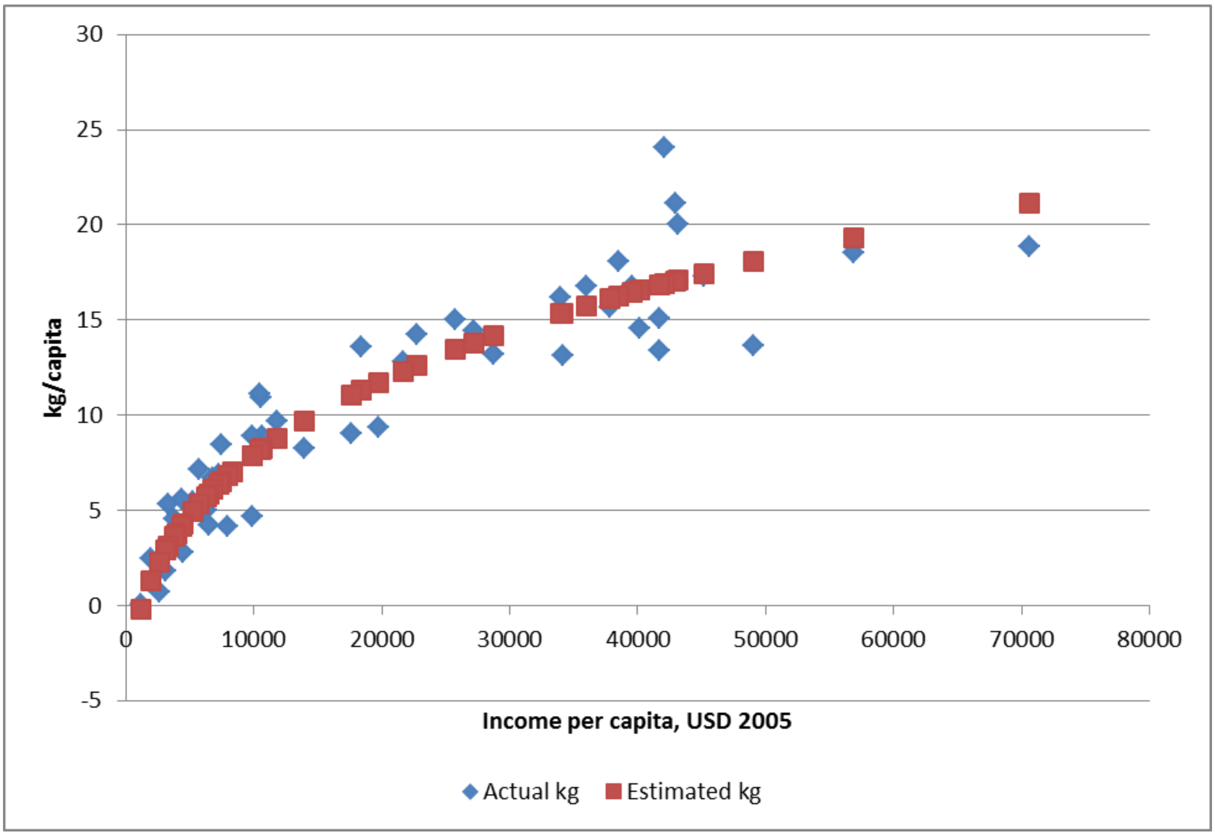

Figure 14. Consumption on household and sanitary papers and income per capita in the individual EFI-GTM countries in 2010. The points "estimated kg" depict the consumption at various income levels as suggested by an estimated function used in the scenarios to defined reference consumption levels. Data from RISI, FAO and World Bank.

6.1.3.4 Printing and writing papers

The demand for printing and writing papers has declined in high income OECD-countries since the start of this century. This has been largely connected with consumers' shift to use electronic media. There is no reason to believe that this tendency will change course in the future when technologies for using media via electronic channels and platforms continue to advance technically and to become more and more affordable at the same time. Hence, even if future consumption quantities followed their past trends, the total consumption of printing and writing papers in the world would not increase drastically by 2030. This is because the increase in low income countries is partly offset by the decrease of consumption in low income countries. Figure 15 pictures observed demand for coated papers in some regions.

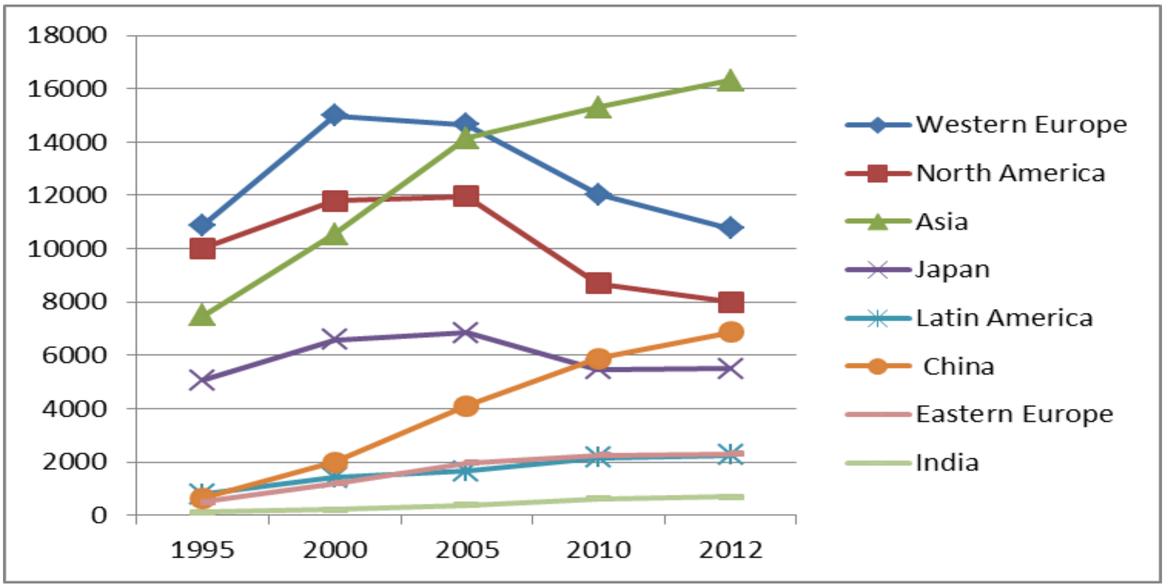

Figure 15. Consumption of coated magazine and fine papers in selected regions, countries and points of time. 1000 tonnes. (Data from RISI).

While the demand of printing and writing papers has still been increasing in developing regions, these markets have been expected to mature more rapidly due to increasing market penetration of electronic media. Hence, the past per capita consumption levels seen in developed countries are not necessarily reached despite the increasing income levels. As seen in Figure 16, correlation between the per capita consumption and the per capita GDP has become less evident during the recent years.

The decline in the per capita consumption seen in the high income countries might level off at some point. So large uncertainty prevails in the future demand for these papers. Only issue that seems to be somewhat sure is that the consumption per capita will decline also in the near future in the wealthier countries. The open questions are to how low will the demand go, and how fast, when and if at all the developing countries start moving to the same direction. No thorough statistical analysis of these issues was available and it was beyond the magnitude of this study do such study addressing all the grades and individual countries in the model used. Therefore some simple and heuristic rules of thumbs were chosen to form the scenario assumptions for demand.

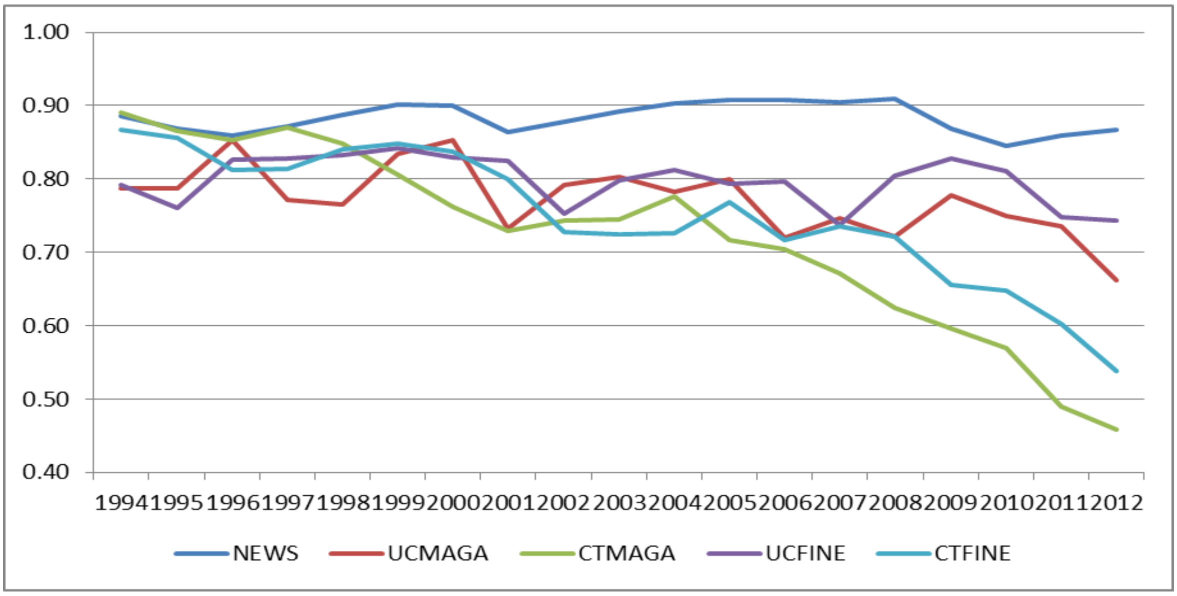

Figure 16. Correlation coefficient between per capita consumption and per capita GDP over time (in USD2005) in 45 EFI-GTM countries for which the data were available for 1994-2012. (News= newsprint, UCMAGA=uncoated magazine paper, CTMAGA=coated magazine paper, UCFINE=uncoated fine paper, CTFIN=coated fine paper)

For each year of the sample of 2000-2014 and for each of the five grades (see Table 5), we examined linear regression functions specifying the demand per capita as a function of GDP per capita. The demand per capita in high income countries is declining and this is decreasing the slope of such functions over time. For each grade, we examined the change in the slope and coefficient over time and projected such change to continue up to 2025. While the actual observations of the demand were typically differing from the forecasted one also in the past as not all the observations are in line as can be seen in figures 17 and 18, we updated the future reference demands in pace of their forecasted change as a response to GDP and population change in the scenarios. The reference consumption levels were updated like this up to 2025. Thereafter the consumption per capita was assumed to remain steady. The global totals are given in Table 5.

6.1.3.5 Other papers

The other papers form a mixed group of papers and paperboard for which the grades, production technologies and the respective demand and supply functions are not straightforward to specify. Often, these are niche grades produced with very low scale and also old paper machines. We assumed that the demand for these papers remains constant over time.

6.1.4 Power, heat and liquid biofuels made of wood biomass

The demand for wood for production of heat and power and liquid biofuels was obtained as an input from TIMES-VTT-model runs. The projections of the two models, TIMES-VTT and EFI-GTM, were iterated to improve the consistency of the projected demand and supply of wood biomass for energy given the market price projections

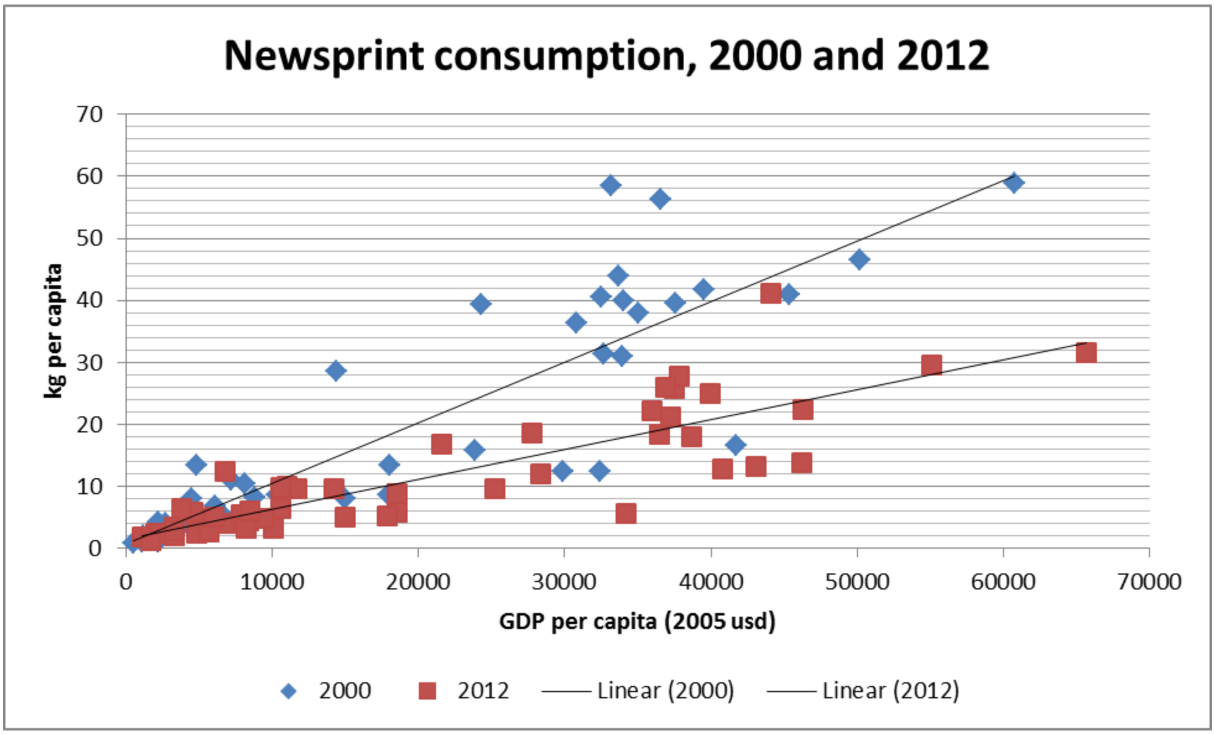

Figure 17 Consumption of newsprint and GDP-per capita pairs in 2000 and 2012, and the corresponding linear functions (Data from RISI, FAO and World Bank).

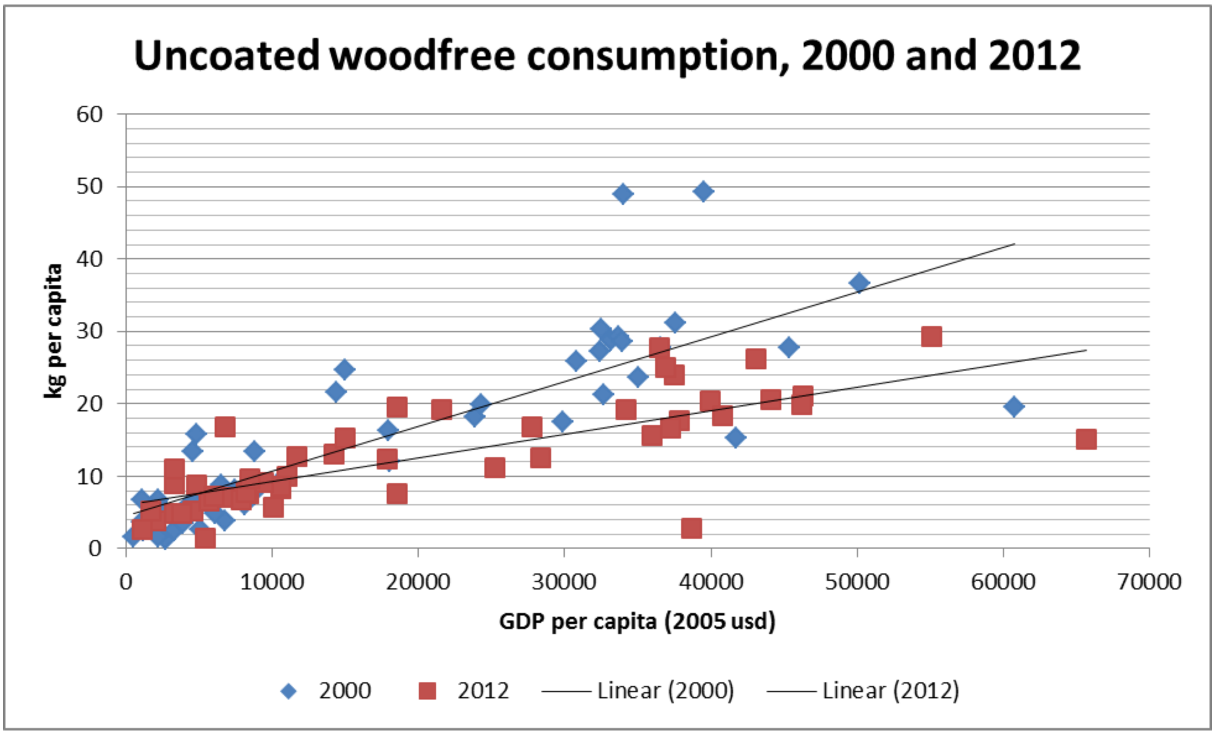

Figure 18 Consumption of uncoated woodfree and GDP-per capita pairs in 2000 and 2012, and the corresponding linear functions (Data from RISI, FAO and World Bank).

6.2 Additional plantation wood and shift in fuel wood use

6.2.1 Shift from traditional to modern fuelwood

The data for regional round wood harvests in the base year 2010 were taken from FAO's statistics. In this data set, fuel wood largely consists of traditional fuel wood used by households. Yet, burning fuel wood in household stoves is not only inefficient in terms of fuel to final energy conversion, but it also leads to the release of small particles and other constituents that are damaging to human health. Indeed, indoor smoke of solid fuels brings in a health risk ranked ten in the list of factors causing premature death in the world (Smith, 2006). We assumed that while the living standards in the developing countries improve, more and more of this traditional fuelwood will be burned in modern heat and power plants. Technically, we assumed that certain percentage of traditional fuel wood can be released for production of modern bioenergy. In the developing countries, we assumed that this share would increase annually so that about 70% of the annual harvests of traditional fuel wood observed in 2010 could be shifted to be used as modern fuel wood by 2050. The respective share for developed countries was assumed to 46% by 2050. These shares are crude scenario assumptions without any empirical modeling behind. The use of fuel wood in the developed countries was assumed to be less affected in the scenarios, because we considered that in the developed countries, the use of fuel wood is less often a necessity but rather a lifestyle choice. Thus is will not be so much affected by the development of alternative more efficient options for energy production.

6.2.2 Increase in forest plantations

It was beyond the scope of this study to do a thorough analysis of the development of area of planted forests globally. Except in China and Latin America, we assumed forest area to remain constant.

Indufor (2011) estimates that the area of forest plantations might grow from 12.8 Mha in 2012 to circa 17 Mha by 2022 and further to about 27 Mha by 2050 in Latin America. In the projections with the forest sector model, we assumed that the plantation areas in Brazil, Chile, Argentina and the rest of Latin America may increase by 14 Mha up to 2050. The actual amount planted was let to be decided by the model depending on wood demand and the plantation costs. This area could be used either to produce fast growing hardwood pulpwood or biomass for energy.

Large uncertainty prevails even over the existing area of planted forest available for wood production in China. Also, there are frequent conflicts concerning new plantation developments (Indufor 2011). We assumed that planted forest area may increase by 2 Mha in China by 2020. The assumption relieves considerably the pressure in the wood supply caused by bioenergy demands in the projections.

7 Energy system results

7.1 Results on the global level

The global total primary energy consumption was about 520 EJ in 2010. Figure 19 illustrates the development of the total primary energy consumption in the Baseline and Best scenarios until 2050. Despite the assumed sustaining growth in the global economy, the increase in total primary energy requirements is relatively modest already in the Baseline scenario, where the total consumption is about 640 EJ in 2030 and about 820 EJ in 2050. Overall, the growth in primary energy is 22% by 2030 and 56% by 2050. On the global level, the growth is thus even accelerating in the later decades, which is caused by the high-growth emerging economies starting to dominate global energy use.

When comparing the growth in energy use to the growth in GDP, it is clear that substantial energy efficiency improvements occur already in the Baseline scenario, where the growth in global GDP is 105% by 2030 and 210% by 2050. Because in the three Best scenarios the economic growth was assumed somewhat slower, the growth in primary energy consumption is somewhat smaller already due to the lower economic activity. However, additional efficiency improvements occur in the Best scenarios also due to the assumed climate policies.

In comparison to the 2014 Energy Technology Perspectives (ETP) scenarios, the Baseline primary energy consumption is clearly lower than the ETP-6DS scenario (no additional policies), but quite close to the 4DS scenario leading to at most 4°C warming (IEA 2014b). The difference is largely explained by global economic GDP development by 2050, which is already 13% lower in the Baseline scenario and as much as 25% lower in the Crunch scenario compared to GDP in the ETP scenarios. On the other hand, both in the Bio-Inno and Bio-Stor scenario the total primary energy consumption is somewhat higher than in the

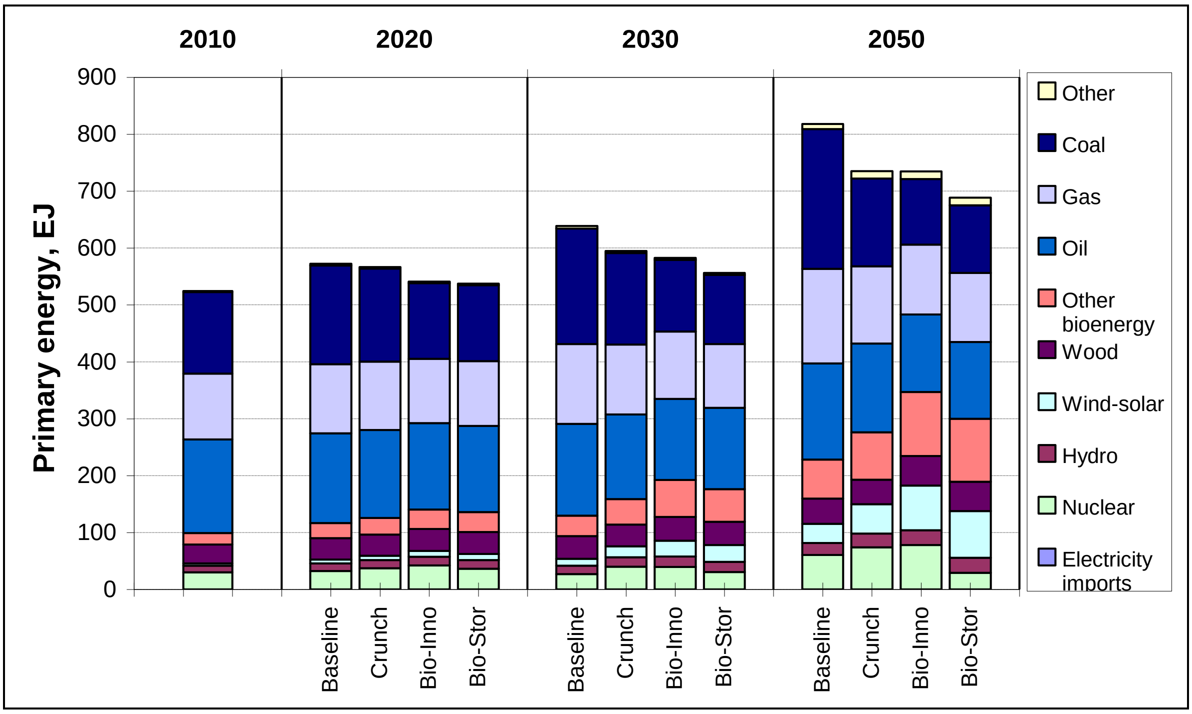

Figure 19. Global primary energy supply in the scenarios.

ETP 2DS scenario. Therefore, on the whole the Best scenarios can be considered to be in a relatively good agreement with the ETP (2014) scenarios.

In 2010, mineral oil was still the most important source of primary energy, with a share of about 32%. Coal was the second most important source (27%) and natural gas the third (22%). In all Best scenarios, the importance of oil is slowly decreasing already between 2010 and 2030, and more steeply afterwards. At the lowest, the share of mineral oil is about 18% in 2050. The share of coal increases in the Baseline, but decreases in all other scenarios. Natural gas either maintains its share (Baseline, Crunch) or loses some of its share (Bio-Inno, Bio-Stor).

While the contribution of fossil fuels to the energy supply is thus decreasing, especially under global climate policies, the use of renewable energy is increasing substantially in all the scenarios. The most remarkable increases are projected in the utilization of solar energy, as one can see from the results in Figure 20. Compared to 2010, the total use of bioenergy increases by 60–100% by 2030 and 140–210% by 2050, and the highest increase are seen in the Bio-Inno scenario. Concerning wood biomass, the assumed sustainable potentials limit the global increase to below 50% in all the scenarios, reaching 50 EJ in 2050. However, through an efficient utilization of agricultural residues and extensive energy crop production, bioenergy can maintain its position as the most important renewable energy source until 2050.

As mentioned in the previous sections, the total potential for energy crops has been estimated to be about 95 EJ in 2050, while the potential of agricultural residues and energy wood have been estimated both at about 34 EJ. In the scenarios the maximum uses are 73 EJ of energy crops and 30 EJ of residues in 2050, which means that about 80% of the potentials should be taken into use by 2050. However, in the Best scenarios we have not

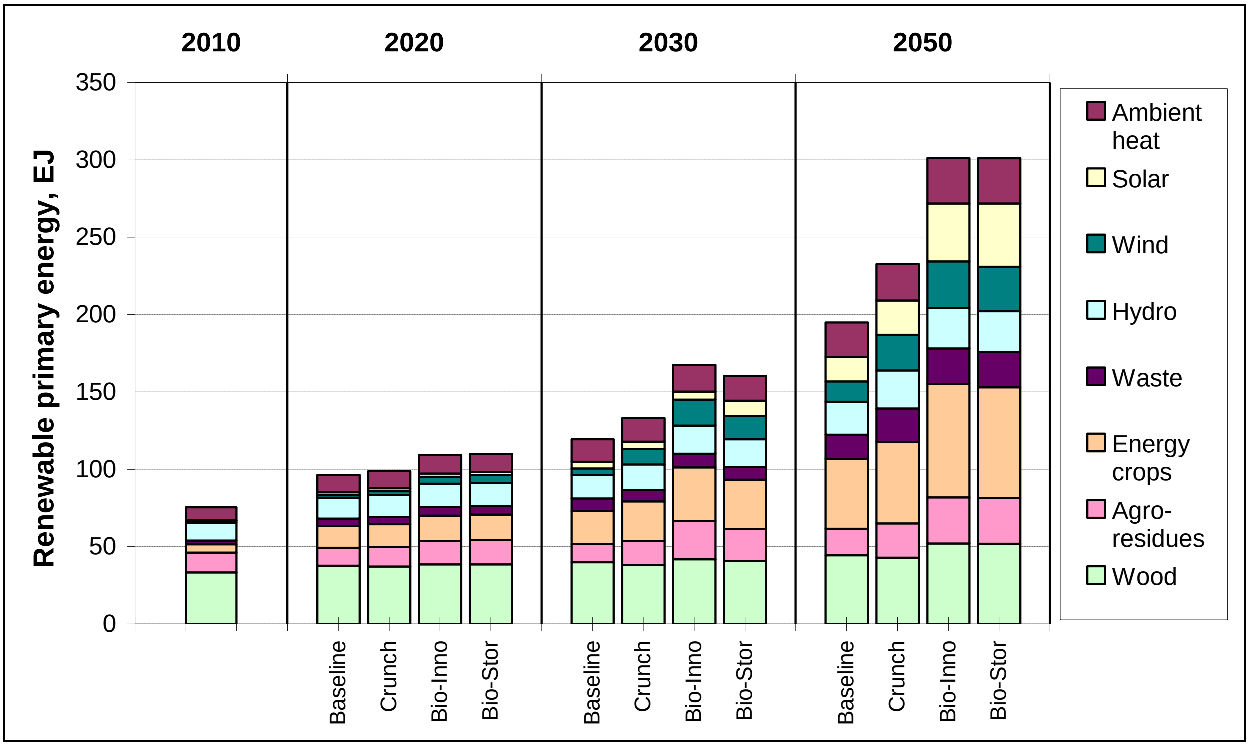

Figure 20. Global supply of renewable primary energy.

taken into account possible future source of bioenergy and biofuels, like algae and other microorganisms, which might change the picture in the longer term.

The total agrobiomass utilization level is in good agreement with the Base estimate in the IPCC SRREN (IPCC 2012). After bioenergy, under global climate policies solar energy becomes the second most important renewable energy source by 2050, passing wind energy around 2040. The utilization of ambient heat (geothermal, heat pumps) also becomes very increasingly important by 2050.

In the global final demand of energy, the share of electricity from total final energy has been steadily increasing in the past decades from 11% in 1980 to over 18% in 2012, which is often called electrification of energy use. This trend is expected to continue, and is reflected in the growth of the global electricity supply, as illustrated in Figure 21. While the global total electricity supply was about 20 PWh in 2010, according to the results it increases by 50% to around 30 PWh in 2030. Electrification is thereafter further intensified, leading to a growth of 140–160% in total electricity generation by 2050, compared to the 2010 level.

Coal is at present globally the most important energy source in electricity generation, and according to the results, in all scenarios it will remain the most important source until 2030, even under global climate policies. The role of natural gas becomes somewhat more prominent until 2020, but then starts to decline. However, after 2030 the share of all fossil fuel based power production starts to decrease more steeply.

Despite fossil fuels retaining a strong position in the global electricity generation until 2030, renewable energy sources are getting an increasingly important role in all the three Best scenarios. Already by 2030, the share of renewables in total electricity generation increases from the 20% share in 2010 to 31–46% in 2030, the lowest share being attained in the

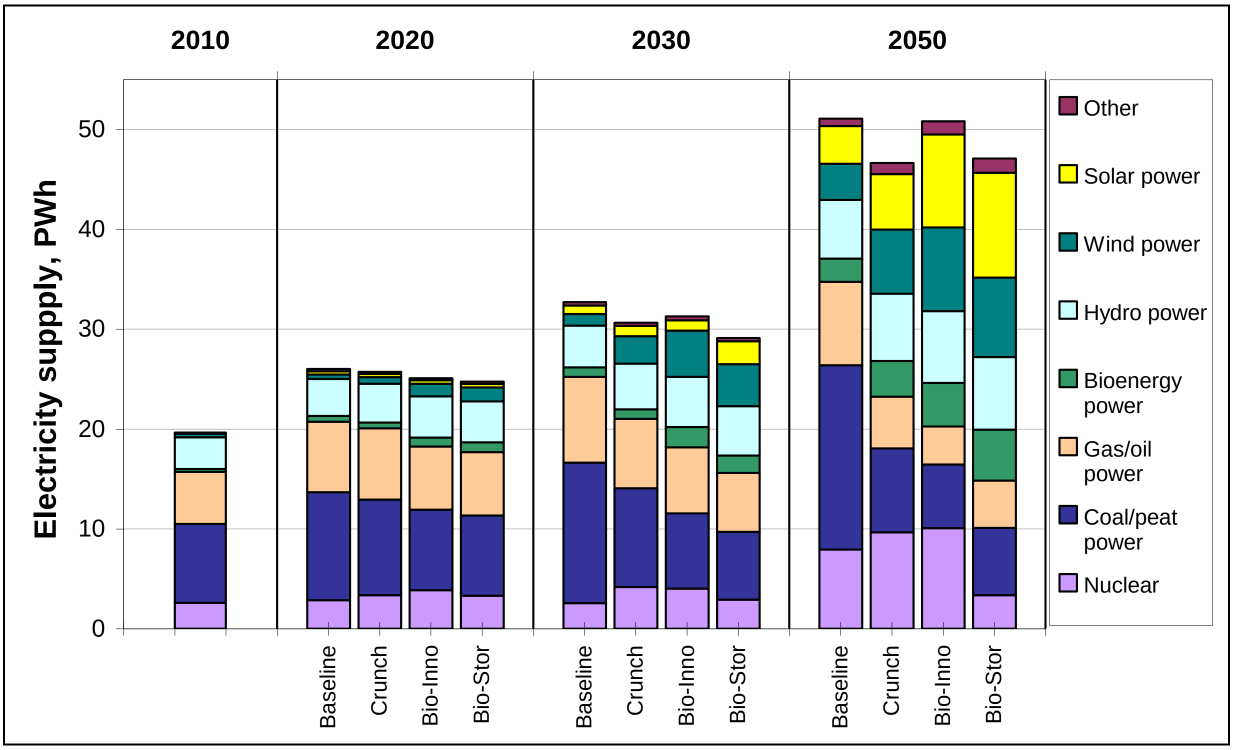

Figure 21. Global total electricity generation.

Crunch scenario and the highest share in the Bio-Stor scenario. By 2050 the share increases further to 50–69%, again the highest share achieved in the Bio-Stor scenario.

On the global scale, the role of bioenergy in electricity generation is at present still very small, in 2010 it accounted for only about 1.5% of all generation. Due to the competing demands for bioenergy, especially with respect to the production of transport fuels, the expansion in the use of bioenergy for power production appears to be much lower than for wind and solar. In the results, the share of bioenergy increases at most to 7% from electricity generation by 2030, and to about 11% by 2050 respectively.

The contribution of different renewable energy sources to the global electricity supply is illustrated in more detail in Figure 22. One can clearly see that, according to the results, by 2030 the largest increase in renewable generation comes from wind power, and between 2030 and 2050 it comes from solar power. However, already during the recent years, solar power has been quickly becoming increasingly competitive, and should the economics continue to improve at a comparable pace, the contribution of solar in 2030 could become higher than the results indicate. Nonetheless, in any case solar energy appears to become among the most important sources for electricity generation by 2050.

In the scenarios with global climate policies, solar power gains a share between 3–8% in 2030 and between 12–22% in 2050 from electricity generation. In absolute terms, the solar power production is in 2030 up to 70 times as large as it was in 2010, while wind power production is up to 13 times and bioenergy power production is up to 7 times as large as in 2010. All these growth rates are very high for the short 20 years' time span. For comparison, between 1990 and 2010 global bioenergy-based power production was only doubled. However, due to the very low present levels, solar power production might, indeed, expand perhaps even more rapidly when boosted by the growing markets especially in the emerging Asian economies.

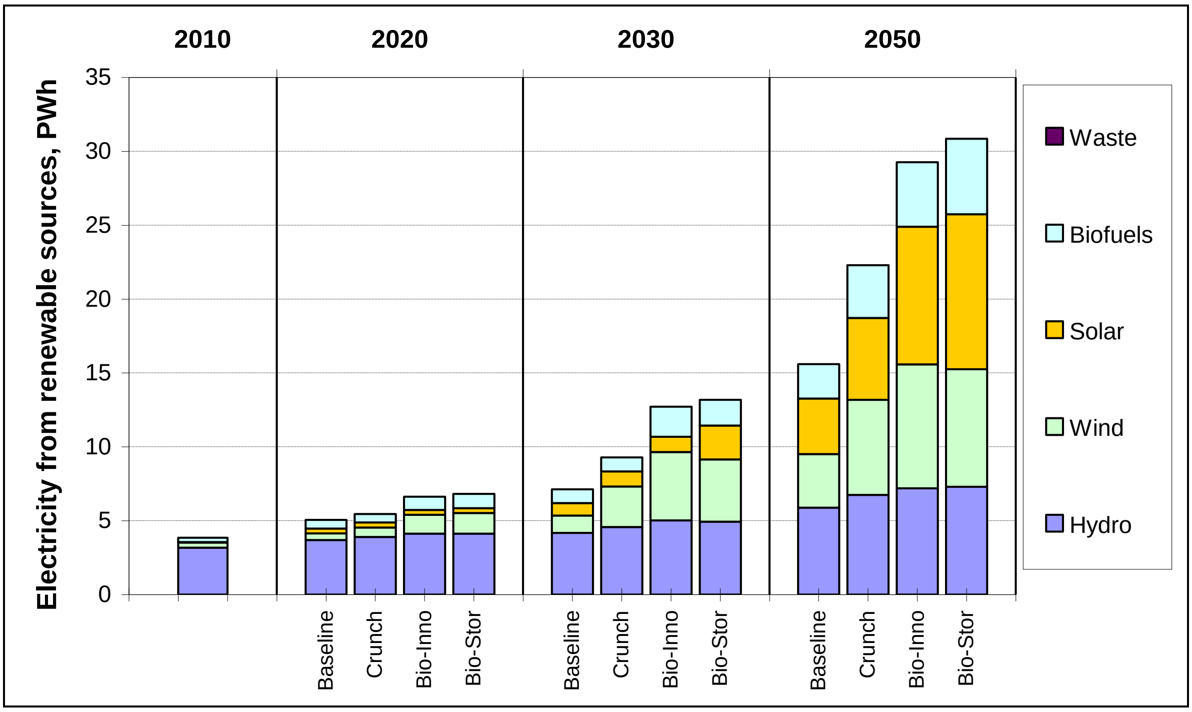

Figure 22. Global electricity generation from renewable energy.

In the Bio-Inno scenario, where rapid development of bioenergy technologies was assumed, global power production based on bioenergy increases most prominently by 2030. The most important technologies that contribute to the growth by 2030 are integrated gasification technologies in the energy sector, and advanced fluidized bed combustion (FBC) technologies and black liquor recovery boilers in the pulp and paper industries, as well as small-scale FBC technologies. Biomass co-firing in large coal power plants also appears to be an important option globally.

In the past, the global demand for bioenergy has always been dominated by the residential and agricultural sectors, where most of the bioenergy has been so-called traditional biomass (firewood, dung, etc.). Although the situation is gradually changing, about half of all bioenergy use may still end up being used in these sectors in 2030, as shown in Figure 23.

As one can see from the results, the transport sector is becoming an important user of bioenergy already by 2030, and still more prominently by 2050. Although electric and/or fuel cell vehicles are expected to have a notable market share at least by 2050, they are not suitable for heavy transports. Consequently, regardless of the penetration of electric vehicles, bioenergy has a large potential in the transport sector, and this potential will also need to be utilized in the scenarios with tight climate policies. According to the results, the use of biofuels in transport would be the highest in the Bio-Inno scenario, where bio-refinery technologies are assumed to become most competitive, and CCS (i.e. BECCS) is also assumed to be available, providing additional business opportunities. However, due to the high prices of mineral oils, liquid transport biofuels appear to become competitive even in the Baseline scenario by 2050 with the assumed technology learning rates for bio-refineries (see

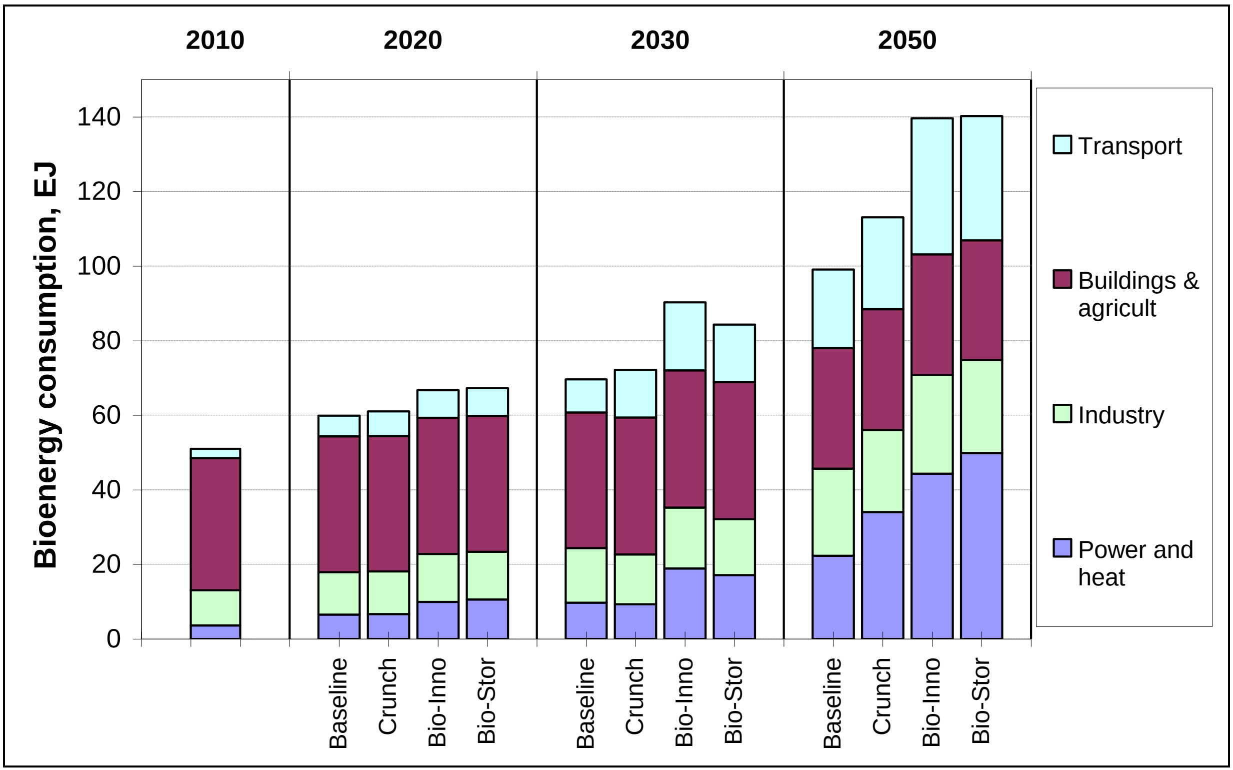

Figure 23. Global bioenergy use by sector (power and heat includes fuels for main activity producer power and heat plants as well as industrial power production).

e.g. Table 4.). However, it should be noted that there are large uncertainties related to the investment costs of the large scale 2nd generation bio-refineries and after the first demonstration plants have been built there will better knowledge on the production costs of second generation liquid and gaseous biofuels from solid biomass.

Power and heat generation is the second highly important sector for increasing bioenergy utilization in the future. While in 2010 the global utilization of bioenergy for power and heat was only about 7% of total bioenergy use (about 3.5 EJ), in 2030 it increases at the lowest to 13% (9 EJ), and at the highest to 22% (19 EJ). In absolute terms, global bioenergy-based power production is thus between 2.5 and 5 times higher than in 2010, which creates substantial markets for new technologies. The increase in industrial use is only moderate, between 40% and 70% by 2030. Even though the growth of the pulp and paper and wood products industries was on a moderate level in all the scenarios, increasing power-to-heat ratios and expanding use in other industries create additional growth in the industrial consumption.

As illustrated in Figure 24, bio-refineries producing liquid or gaseous biofuels from solid biomass represent one of the key technology clusters that in the future bioenergy market. In particular, high quality liquid fuels for the transport sector are projected to have a highly expanding global market within the next few decades.

In a vision presented in the IEA Biofuel Roadmap (IEA 2011), global transport biofuel supply grows from 2.5 EJ in 2010 to 32 EJ in 2050 (biodiesel, biojet, ethanol). The demand increases in all regions, and the share of biofuels in total transport fuels would increase from 2% to 27% in 2050. In our scenarios, the use of biofuels in the transport sectors grows to 24.6 EJ in the Crunch scenario, 33.4 EJ in the Bio-Stor scenario and 36.5 EJ in the Bio-Inno scenario by 2050. The results in the global climate policy scenarios are thus slightly higher

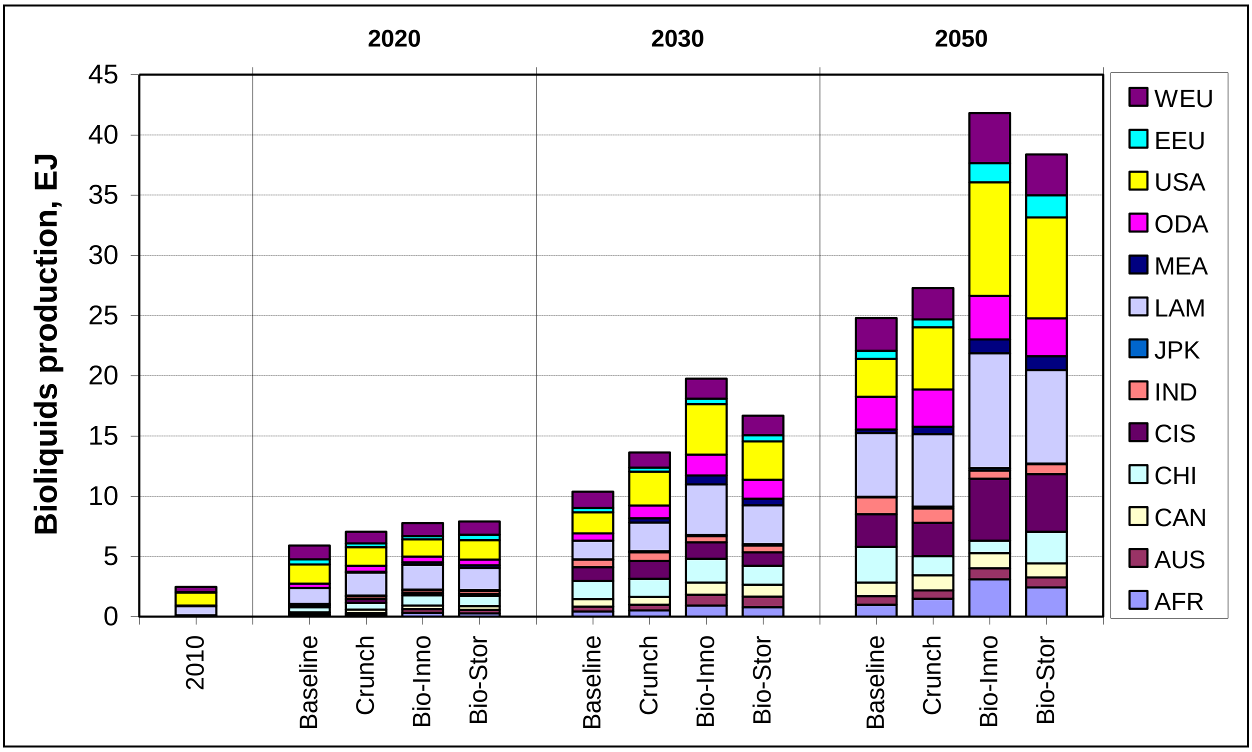

Figure 24. Global production of liquid biofuels.

with respect to biofuel penetration, but quite close to the IEA vision. Biofuels would thus account at most about one third of total transport fuels by 2050.

However, as liquid biofuels can be well utilized also in the other sectors, like to replace mineral oil in boilers and residential heating, the total liquid biofuel production is still somewhat higher in the scenarios, as shown in Figure 24. In the Bio-Inno scenario, the production grows to about 20 EJ already in 2030, and subsequently to over 40 EJ in 2050. Availability of biomass becomes a critical concern for the highest biofuel utilization scenario. By 2050 the projected biofuel production in the Bio-Inno scenario would consume around 75 EJ of primary biomass. That represents almost 50% of total primary biomass use at that time, and well exceeds the current global biomass use. Sustainability of the large scale biomass fuel supply is an obvious precondition for the feasibility of these scenarios.

The possibility of using bioenergy in combination with carbon capture and storage (BECCS. is one of the key factors improving the competitiveness of bio-refineries under tight climate policies. The idea behind BECCS is that by capturing the CO_2 streams from biofuel refining processes and injecting it into a long-term geological storage formation can turn the carbon neutrality of bioenergy even into negative emissions (IEA 2011b). As the CO_2 streams from biofuel production are relatively pure, the carbon capture process has relatively low costs and comparably small energy losses. Bio-refinery projects could therefore be among the first to implement the CCS technology commercially.

In the Best scenarios, the climate policy targets were set slightly less strict than usually in the so-called 450 ppm scenarios, as the upper limit on global forcing was set to 3.2 W/m^2. For example, e.g. the IEA ETP 2DS scenario assumed 50% reduction in the global CO_2 emissions by 2050, whereas in the Best scenarios Bio-Inno and Bio-Stor lead to about 40% reduction in global CO_2 emissions by 2050. The development of the global GHG emissions is shown in Figure 25. As one can see, total emissions must be reduced by more than 50% from the Baseline to reach the policy targets in the Bio-Inno and Bio-Stor scenarios.

As already indicated above, applying CCS and BECCS appear, indeed, almost necessary for achieving the climate policy targets, roughly leading to at most 2°C temperature increase. The negative emissions from BECCS are not explicitly shown in the figure, but have been subtracted from the energy and industrial sector emissions. The Baseline development clearly shows how challenging the emission reduction targets are, primarily because of the increasing primary energy use for power production, industry and transports. In addition, also other GHG emissions, mainly from agriculture, tend to increase, and are among the most difficult to reduce. In order to compensate for those sectors where the reductions are very expensive, it appears to be highly useful to reach negative emissions in the energy sector. Until 2030 the role of CCS remains small, in total at most 2 Gt(CO_2), but in 2050 total volume of CCS grows up to about 7 Gt, of which about 40% is based on bioenergy. The differences in the total volume are quite small between the Bio-Inno and Bio-Stor scenarios.

At the moment there are large uncertainties related to the implementation of the CCS technologies and many of the planned large scale demonstration projects have been cancelled. In the Best scenarios, we have assumed, anyway, that the CCS option would be available for GHG mitigation when it becomes competitive compared to the other mitigation options (i.e. mainly after the year 2030). The largest concern is related to the industrial emissions, like GHG emissions from steel and cement industries, which would be very difficult (or even impossible) to tackle without CCS. Biomass could be used in steel industries to replace coal as a reducing agent but the amount of biomass required would be so high that it is not possible in practice. As a result, at least BECCS would be needed to compensate those GHG industrial emissions that are impossible to cut without CCS. Another option is to use alternative materials (i.e. like replace cement with other materials) or change the whole production process (like use hydrogen instead of coal in steel making).

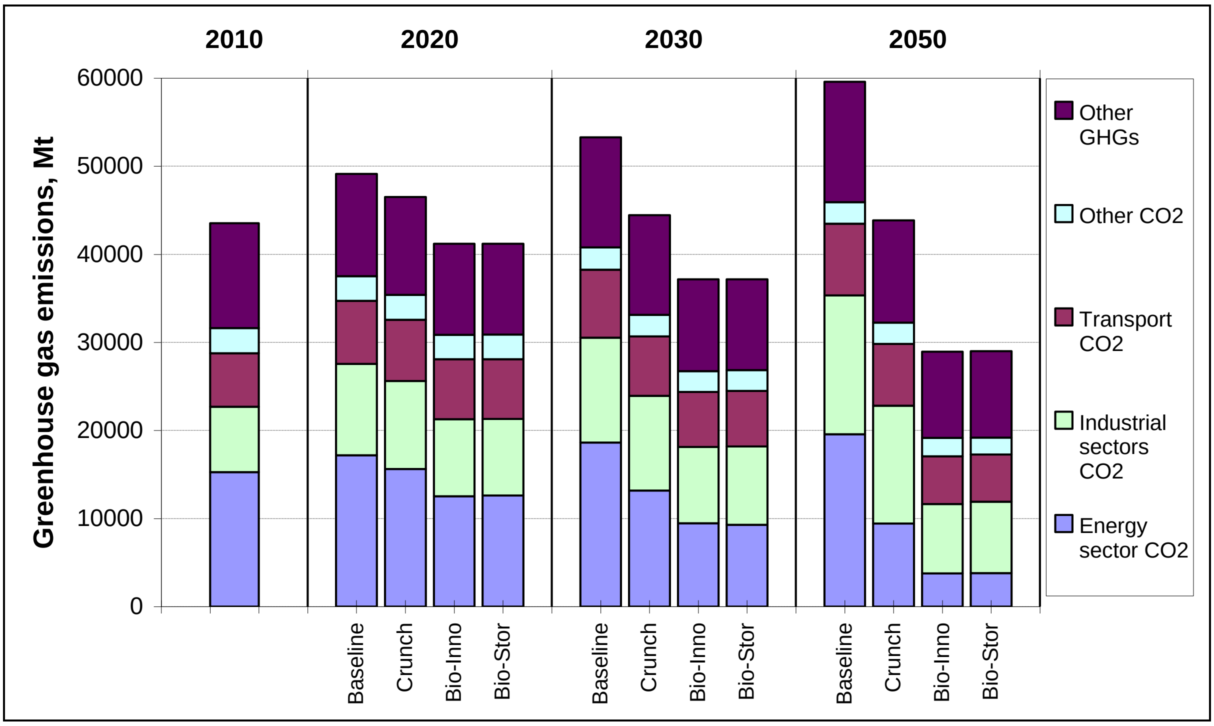

Figure 25. Development of global greenhouse gas emissions.

7.2 Results for Europe

In Europe, total primary energy consumption has been slowly decreasing already during the past few years. The highest recorded consumption was in 2006, 83 EJ, while in 2012 it had dropped 7% from that to about 77 EJ, partly due to economic recession in some countries. As the population is not expected to grow in the future, and the economic growth focuses on services and light industry, total energy consumption is projected to decline also in the future along with continuous efficiency improvements, as shown in Figure 26.

Oil is at present the most important energy source in Europe, accounting for 36% of primary energy. However, by 2050 the dependency on mineral oil reduces strongly, down to about 20% of primary energy. Natural gas and coal are the second and third most important energy sources, both used extensively in power generation and industry. According to the results, they both maintain a rather strong position until 2020, but thereafter start to decline in the same way as oil consumption. Nuclear power contributed to about 13% of primary energy in 2010, and its role is decreasing until 2030. However, the results indicate that by 2050 nuclear power may regain its competitiveness in Europe under tight climate policies. Nonetheless, in the scenarios the amount of nuclear generation is at most returning to the 2010 level. However, it should be noted that there are large uncertainties related to national nuclear policies today and also in the long term. In the Best scenarios, those countries which have already made a decision not to invest to new nuclear (or phase down the existing plants like in Germany) would not invest in nuclear in the future either.

The most important energy source replacing oil is bioenergy, either through producing liquid biofuels in Europe or by importing them. According to the results, the increase in bioenergy use could be even larger in magnitude by 2030 than the increase in solar and wind energy, in primary energy terms. In the Bio-Inno scenario, total bioenergy use (without waste) increases

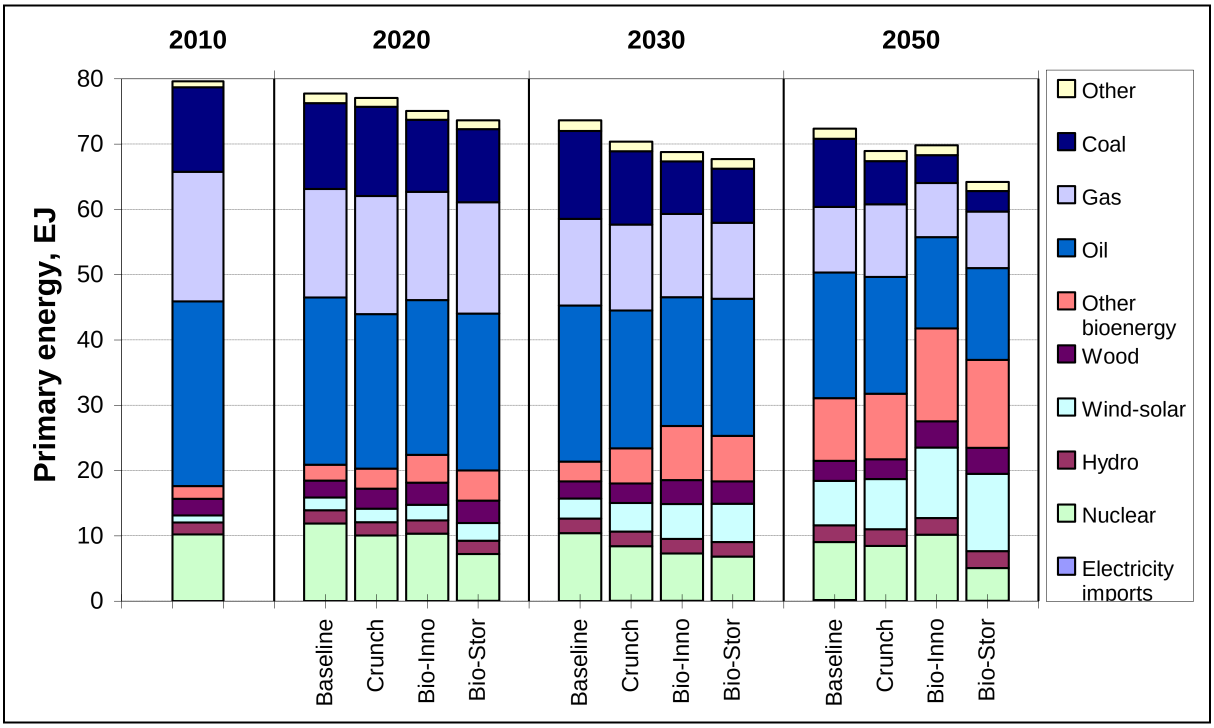

Figure 26. Primary energy supply in Europe (including bunkers).

from 4.5 EJ in 2010 to 12 EJ in 2030. Most of the increase is covered by agricultural residues and energy crops, which increase from 1.5 EJ to 7.5 EJ in 2030. With the growth in the demand for liquid biofuels continuing until 2050, energy crop production increases further. The use of wood biomass expands by at most 1 EJ in by 2030 and by 1.5 EJ by 2050.

A more detailed summary of renewable bioenergy is shown in Figure 27. Total primary supply of bioenergy was in Europe about 5 EJ in 2010, i.e. only about 6% of total primary energy. Wood biomass contributed to about 2.7 EJ, biogas 0.4 EJ, renewable waste about 0.4 EJ, and agrobiomass about 1.5 EJ (including agricultural residues and energy crops). However, due to the statistics on the split of solid biomass into different sources being somewhat inadequate, these are own estimates based on a number of different sources.

According to the results, the use of wood biomass for energy may increase up to about 4 EJ, mainly by enhanced use of forest residues from final fellings and supplementary thinnings. Compared to the increase in agrobiomass use, the role of wood biomass for increasing the use of renewable energy appears to be rather small in Europe. However, the total contribution from bioenergy increases in the scenarios from about 5 EJ up to about 12 EJ in 2030 (Bio-Inno), and bioenergy would thus remain the largest source of renewable primary energy in Europe. Until 2030, the results can be viewed to be in good agreement with the estimated demand for biomass for energy in the EU countries based on national renewable energy projections, totalling in about 10 EJ already in 2020 (Bentsen & Felby 2012). One should also note that a small part of the bioenergy supply is covered by imports, which reaches its highest level in the Bio-Inno scenario in 2030, 1.3 EJ.

When moving beyond 2030, agrobiomass supply becomes increasingly important in all the scenarios. At the highest, the total bioenergy supply reaches almost 20 EJ in 2050, including 10 EJ of energy crops, 4 EJ of wood biomass, 2.8 EJ of agricultural residues, 1.2 EJ of

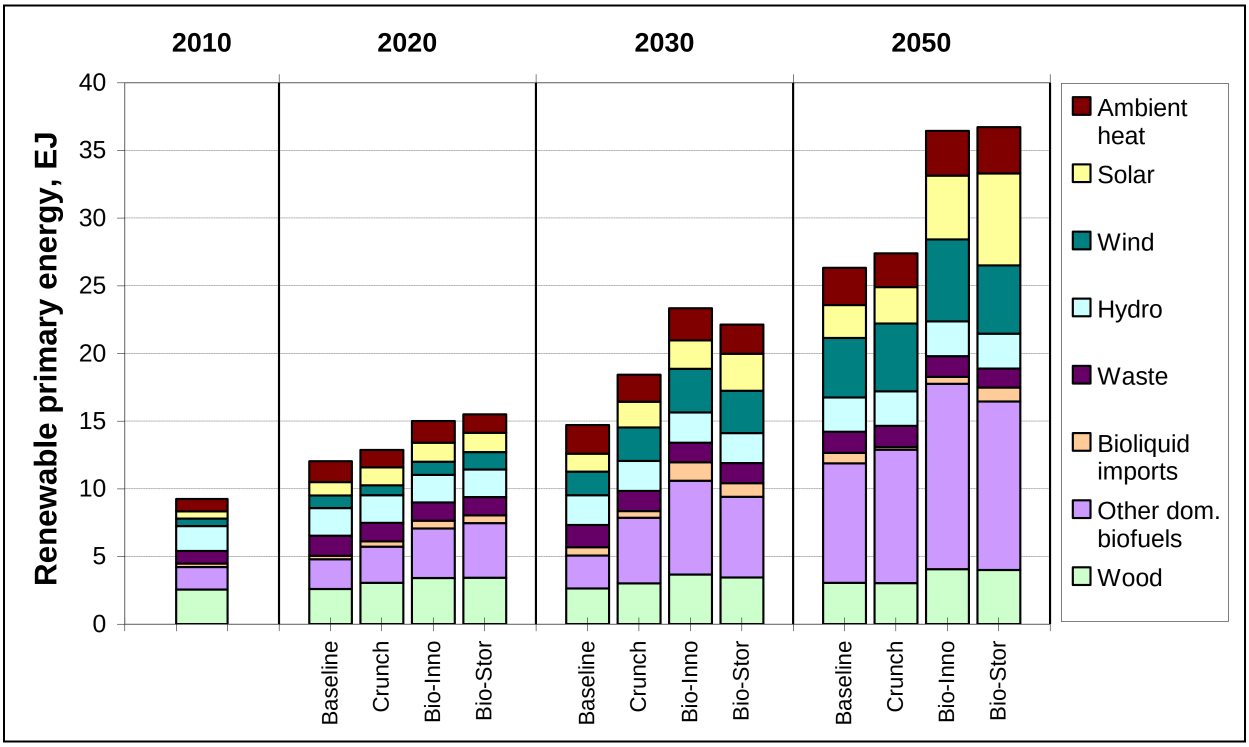

Figure 27. Supply of renewable primary energy in Europe (includes all municipal waste).

biogas, 1 EJ of imported bioliquids, and 0.7 EJ of renewable waste. This means that even in 2050 bioenergy would still account for over 50% of all renewable energy in Europe, despite huge expansions occurring also in the use of wind and solar energy. As expected, the largest increase in solar energy occurs in the Bio-Stor scenario, passing wind energy in importance.

Although total primary energy consumption is expected to decline slowly in Europe, the demand for electricity shows a different trend. Between 2000 and 2012 the total final consumption for electricity increased 11% in Europe. The fact that after 2008 the growth has been practically zero may be attributed to the economic recession in many parts of Europe. In line with these trends, our Baseline still shows a steady but slow growth in electricity demand until 2050. In the Best scenarios the growth is somewhat lower until 2030, due to the differences in assumptions concerning economic growth and climate policies. However, by 2050 the tightening climate policies also have an additional electrifying effect on energy demand, which is clearly shown in the results in the Bio-Inno scenario.

According to the scenario projections, the total electricity supply would be about 4000 TWh in 2030, as shown in Figure 28. In the Baseline, both coal and gas power retain a strong position in the generation mix, but in the Best scenarios their contribution decreases quite steeply. On the other hand, the largest expansions occur in wind and solar power. Wind power would account for 18–24% of total electricity supply by 2030, and the corresponding share for solar is between 7–13%. For both wind and solar power, the results are within the range of estimates on the realizable potential in Europe by 2030 (e.g. EC 2014).

The decrease in fossil fuel based power generation becomes quite remarkable after 2030 in all of the three Best scenarios. In the Bio-Inno and Bio-Stor scenarios, the share of fossil generation drops even below 5% in 2050, while the share was still as high as 51% in 2010. Such a low share of fossil fuel based thermal power generation would, of course, tend to

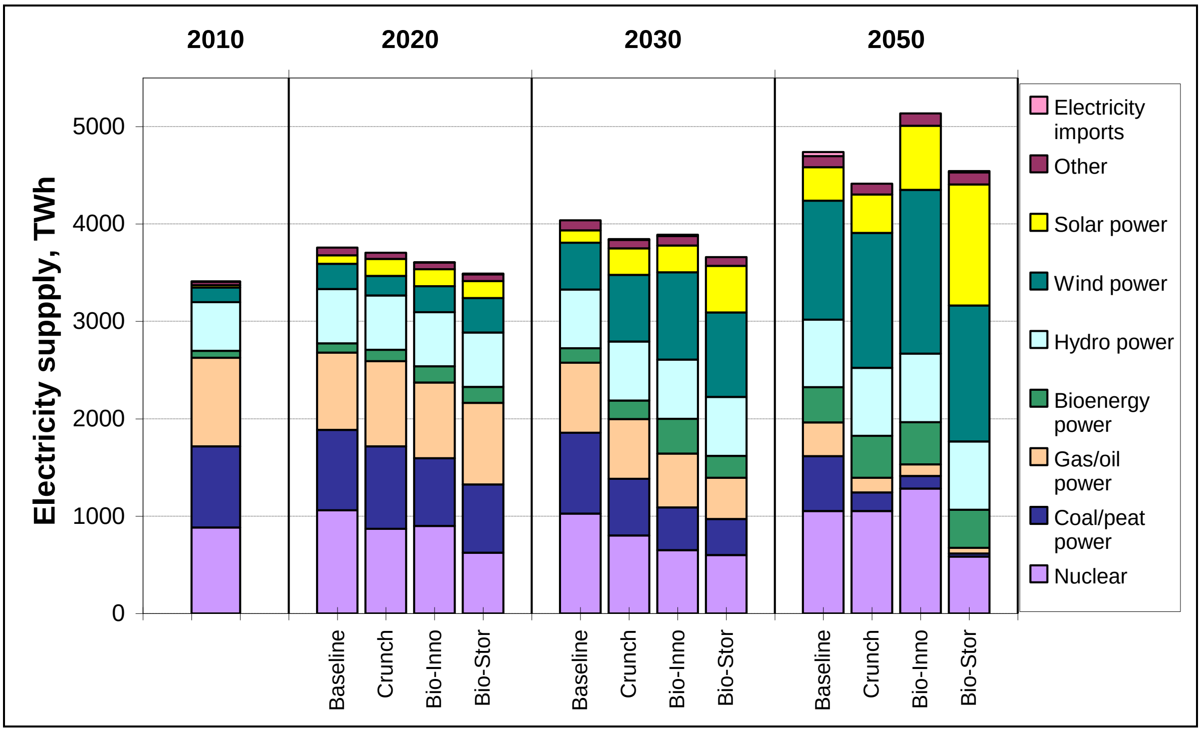

Figure 28. Total electricity supply in Europe.

reduce the flexibility of the production system, and should be compensated by other options introducing balancing and peak power into the system when necessary. In the model the peak power requirements are met by requiring investments into additional reserve capacity or storage, but the model is undoubtedly too coarse to simulate these in a realistic way when integrating such high amounts of variable generation into the system.

The contribution of renewable electricity generation to the electricity supply is summarized in some more detail in Figure 29. The figure nicely illustrates the huge increases in renewable generation that are foreseen by 2050, in particular under strict climate policies. In the scenarios, the total share of renewable generation increases up to 60% by 2030, and up to 85% by 2050. In comparison, the share of renewable generation was only 23% in 2010. Such a rapid change in the system requires also quite heavy investments, and phasing out of old fossil based capacity.

According to the results, the increase in bioenergy based electricity generation would also be substantial in Europe, although it may easily get less attention. The modest 3% share of bioenergy power in 2010 is increased in the Best scenarios to 5–9%, the highest share being reached in the Bio-Inno scenario, as expected. On the longer term, the differences in bioenergy generation are reduced, such that in all scenarios the bio-power production is between 390 and 430 TWh in 2050, corresponding to 9–10% of total generation.

The technologies providing the expansion in bioenergy power generation are in the short term mostly based on state-of-the art fluidized bed combustion (FBC) technologies and co-firing options. However, in the longer term integrated gasification technologies start penetrating the market, especially in the scenarios with global climate policies. In addition, pressurized oxyfuel combustion plants equipped with CCS appear to become competitive, as they bring about negative emissions. Finally, due to the high emission prices, also solid-oxide

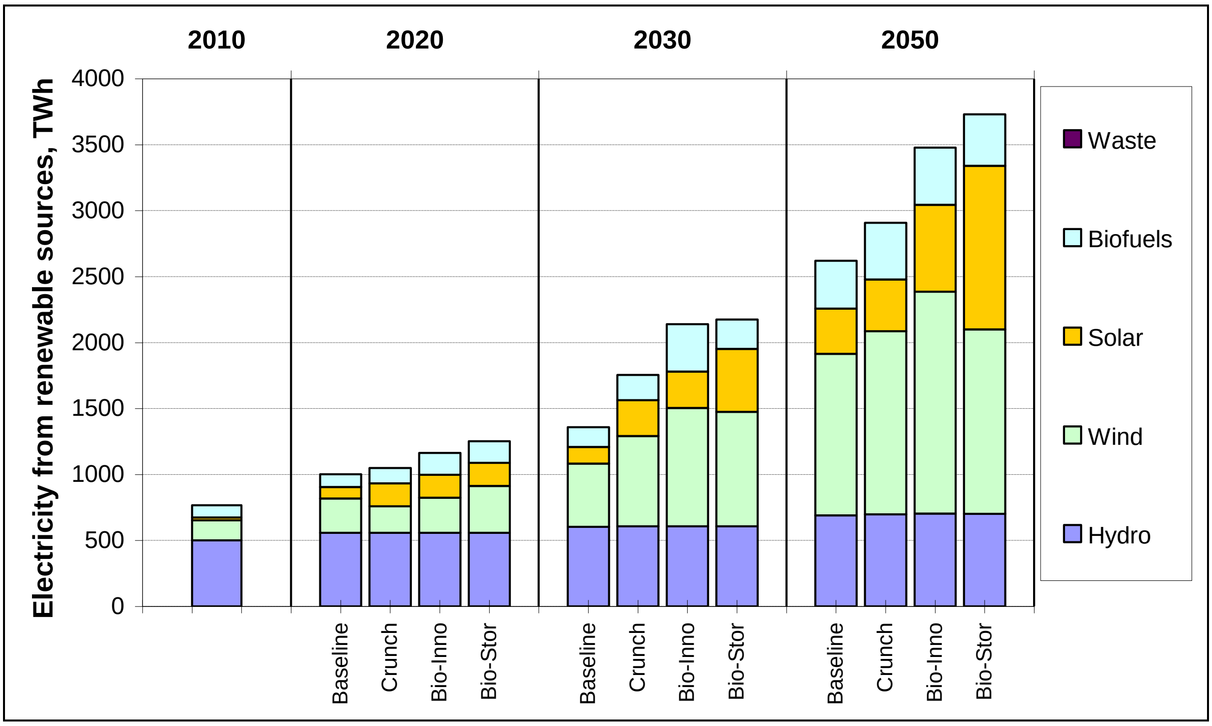

Figure 29. Electricity generation from renewable energy in Europe.

integrated gasification fuel cells start penetrating the power plant market around 2050, and offer unsurpassed power-to-heat ratios for bioenergy power plants. It is evident that especially the deployment oxyfuel combustion with CCS and solid-oxide integrated gasification fuel cells have large uncertainties related to commercialization and costs of mature technologies. In addition, currently there is no policy framework for BECSS either.

Solar power technologies are dominated by PV systems, due to the assumed rapid cost reductions. Solar thermal power plants are thus left in the margin, although they would have much better properties with respect to integrating large amounts of solar power into the European systems. For wind power, offshore systems are inevitably becoming increasingly important in the longer term, as land-use restrictions start to limit onshore wind expansion.

Large integration of variable generation into the European electricity systems would entail also grid enforcements and expansion, additional reserve capacity, and the need for enhanced demand side management. In the energy system model these aspects have been taken into account only in relatively crude ways, for example by defining for each generation technology the capacity credits at peak load times and the required reserve capacity margins. In the resulting total electricity supply capacity, large amounts of wind and solar power will already as such lead to lower average utilization factors in the system. And when reserve capacity requirements are taken into account, the capacity requirements are further pronounced. The results from the Best scenarios are illustrated in Figure 30.

According to the results, the total European electricity supply capacity should increase up to 50% from the 2010 amounts by 2030, when large amounts of solar and wind power are installed (Bio-Stor). Photovoltaic solar power has the highest impact on the capacity, as it has the lowest utilization factors at peak times, but also wind power expansion contributes to the need for higher overall capacity. By 2050, the total capacity should more than double both in the Bio-inno and Bio-Stor scenarios.

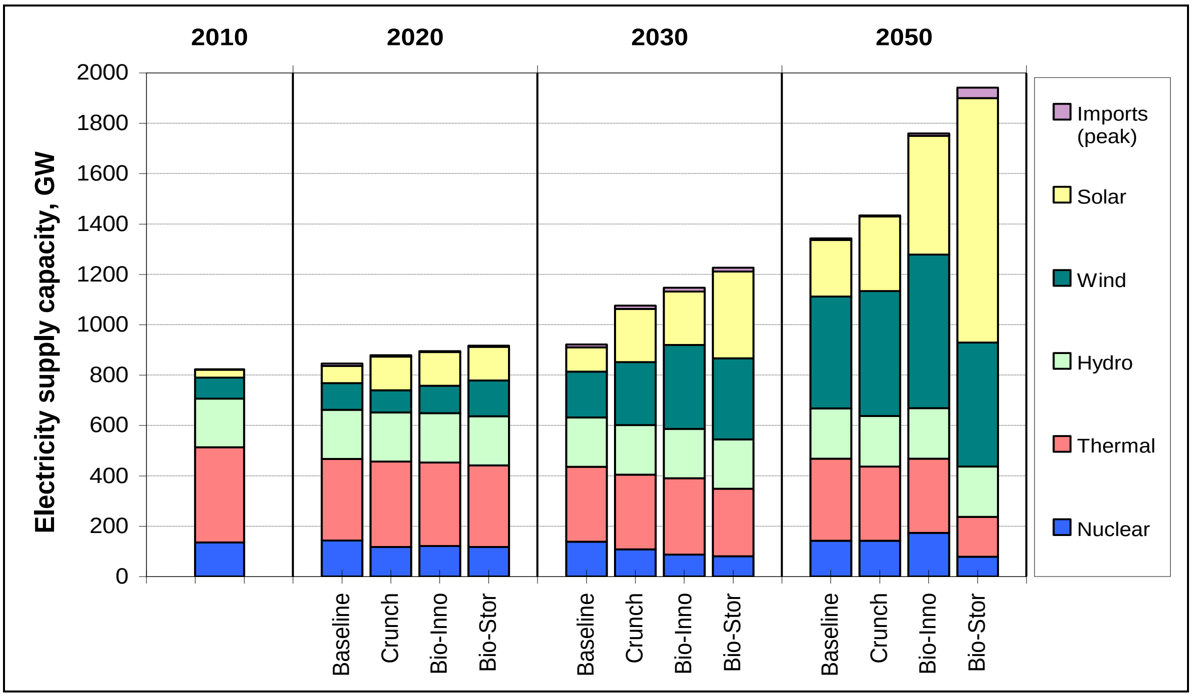

Figure 30. Development of electricity generation capacity in Europe.

Even though the model is deterministic, and is not adequate for capturing the impacts of very large amounts of variable generation, such as those shown for 2050, the results still give a good indication of the large investments involved when striving to move into an electricity system that is highly based on renewable energy. As a thermal energy source, bioenergy offers a dispatchable renewable power generation option, which to some extent can provide flexibility needed in the power system. However, due to the limited bioenergy resources and its competing uses, bioenergy can in any case provide only a small fraction of the balancing power needed in the European energy system with generation mixes in the Bio-Inno and Bio-Stor scenarios. A break-through in energy storage technology is basically needed, as was assumed in the Bio-Stor scenario. Indeed, the storage capacity built in the Bio-Stor scenario becomes considerable, with a discharge capacity of about 150 GW by 2050.

Like on the global scale, even in Europe small scale combustion in the residential and agriculture sectors still at present represents the most important use of bioenergy, as illustrated in Figure 31. According to the results, small scale wood consumption decreases by about 15% by 2030, and 30–37% by 2050. In all other main sectors, the use of bioenergy increases considerably in the three Best scenarios.

The largest increase in the use of bioenergy for power and heat production occurs in the Bio-Inno scenario, where it is quadrupled by 2030, from about 1 EJ to 4 EJ. In the Bio-Stor scenario the growth is similar until 2020, but slows down thereafter much behind the Bio-Inno scenario, partly because the economic growth is lower and partly because other renewable energy technologies develop faster and gain more market share. However, when moving further to 2050, bioenergy use for power production reaches the level of 4 EJ in all three scenarios, which indicates a reasonably robust longer-term result for Europe.

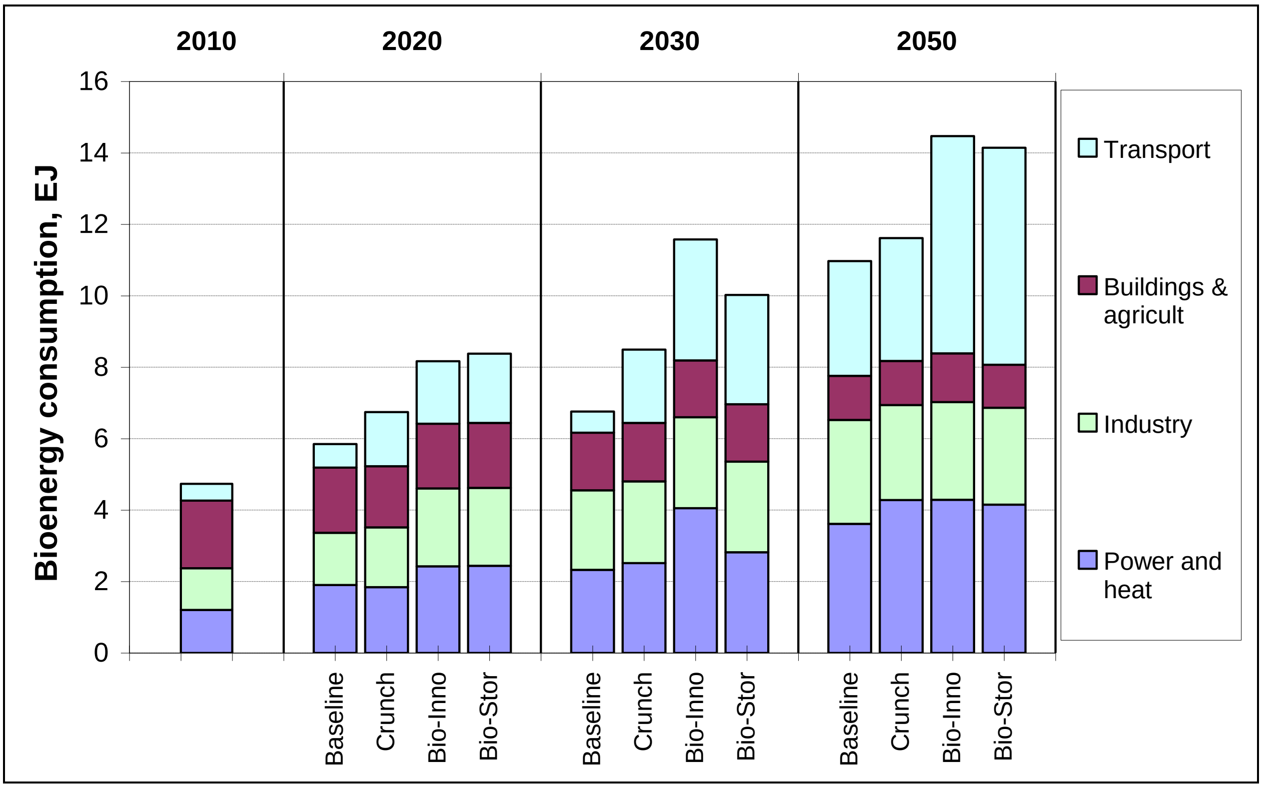

Figure 31. Bioenergy use by sector in Europe.

The biofuel demand in the transport sector may become very important already by 2030, due to the EU 2030 climate and energy policy framework with country-specific targets for the non-ETS sectors. As transport is the largest source of CO_2 emissions outside the ETS sectors, it will be necessary to reach substantial emission reductions already by 2030. And because the hybrid and electric vehicle technologies may not be able to penetrate sufficiently into the car market by 2030, not to speak of heavy transports, drop-in 2nd generation liquid biofuels appear to be the most economical option for achieving substantial non-ETS emission reductions. Despite having the largest penetrations of electric vehicles, the Bio-Inno scenario also shows the highest consumption of transport biofuels in 2030, almost 3.4 EJ, due to the assumed development of bio-refinery technology and the favourable development of BECCS business services.

As described in the scenario assumptions, the 80% GHG reduction target by 2050 in Europe was assumed in the Bio-Inno and Bio-Stor scenarios, while in the Crunch scenario no additional policies were assumed after 2030 (simulated by a constant ETS price after 2030). In the results, the total GHG emissions are decreased to the level of 3000 Mt by 2030 and to 1170 Mt by 2050 (20% from the 1990 emissions). In the Crunch scenario, the 40% GHG reduction target of the 2030 policy is barely achieved, and only modest further reductions occur by 2050. On the European level, the most difficult sectors for achieving deep emission reductions are agriculture, process industry, transports and also the residential sector. The residential sector has a large infrastructure for using natural gas for heating and cooking, which accounts for the most part of the “Other CO_2” emissions remaining in 2050.

From the results for the 2050 emissions one can again clearly see the advantage of achieving negative emissions in some sectors to compensate for very difficult emission cuts in others. In the Bio-Inno and Bio-Stor scenarios, the energy sector and industry are reaching

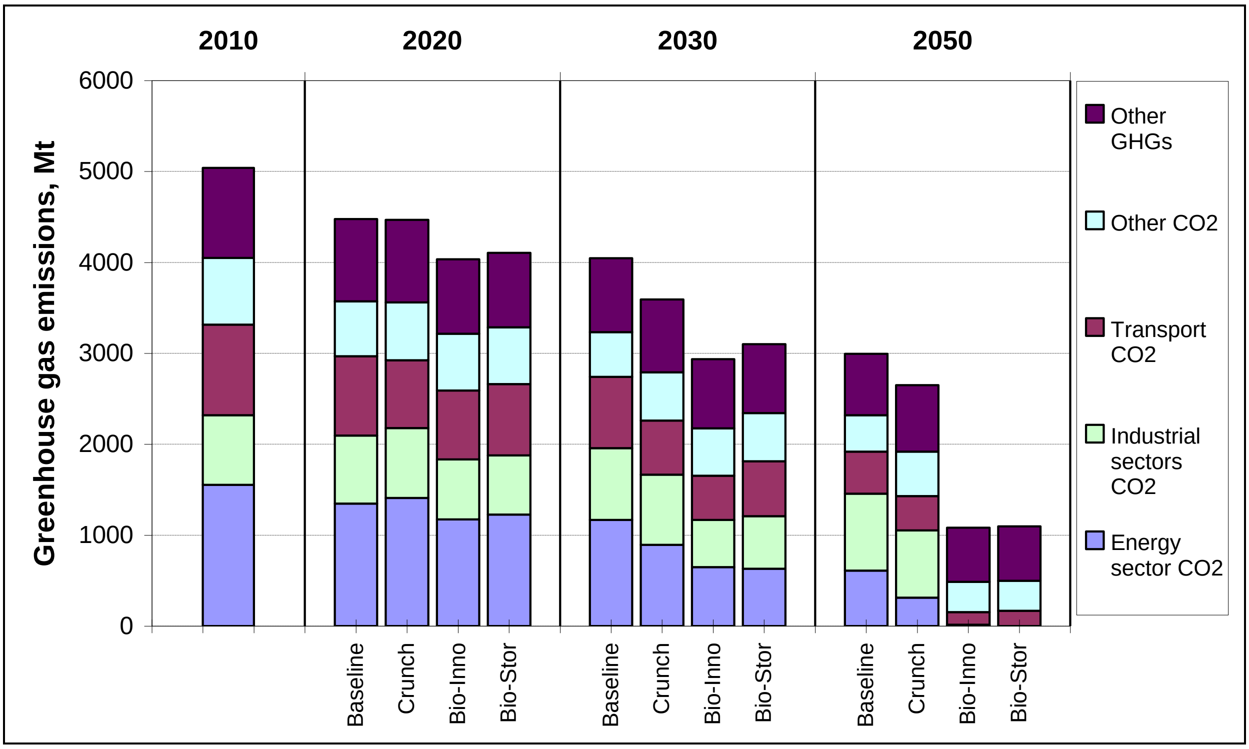

Figure 32. Development of greenhouse gas emissions in Europe.

zero net CO_2 emissions in 2050 due to being credited for the negative emissions achieved mostly by BECCS applications. And, as mentioned earlier, the most economical applications for BECCS appear to be in the bio-refineries, which produce 2nd generation transport biofuels for reducing transport CO_2 emissions. Bio-refineries would thus in practice be able to bring about emissions reductions simultaneously in the ETS and non-ETS sectors.

Concerning the industry sector, the results shown in Figure 32 for 2050 may give a too optimistic impression about the emission reduction potential, because all the negative emissions have been allocated to the energy and industry sector according to their gross emissions, in order to avoid plotting negative emissions. In fact, a large part of the process emissions from basic metal and minerals manufacturing are among the most difficult to reduce, as indicated by the results for the Crunch scenario in 2050.

7.3 Results for Finland

Characteristic features of the Finnish energy system are high energy intensity in all sectors due to the cold climate and dark winters, the importance of energy intensive industries in the economy, and long transport distances. All these factors have also an impact on the most economical mix of energy sources in the primary energy supply. In particular, the forest industry has a central role in the utilization of bioenergy in Finland.

In Finland, the total primary energy consumption was about 1500 PJ in 2010, of which 52% consisted of fossil fuels and peat. The use of renewable energy has already for a long time been at a high level, close to 30% from the primary energy use. The role of nuclear energy is also considerable in Finland, accounting for about 18% of primary energy. The projected future development of primary energy consumption is shown in Figure 33. In the Baseline and Crunch scenarios, total primary energy increases by 2030 about 11% from the 2010 level, but the increase is to a large part attributable to the large increase in nuclear power in

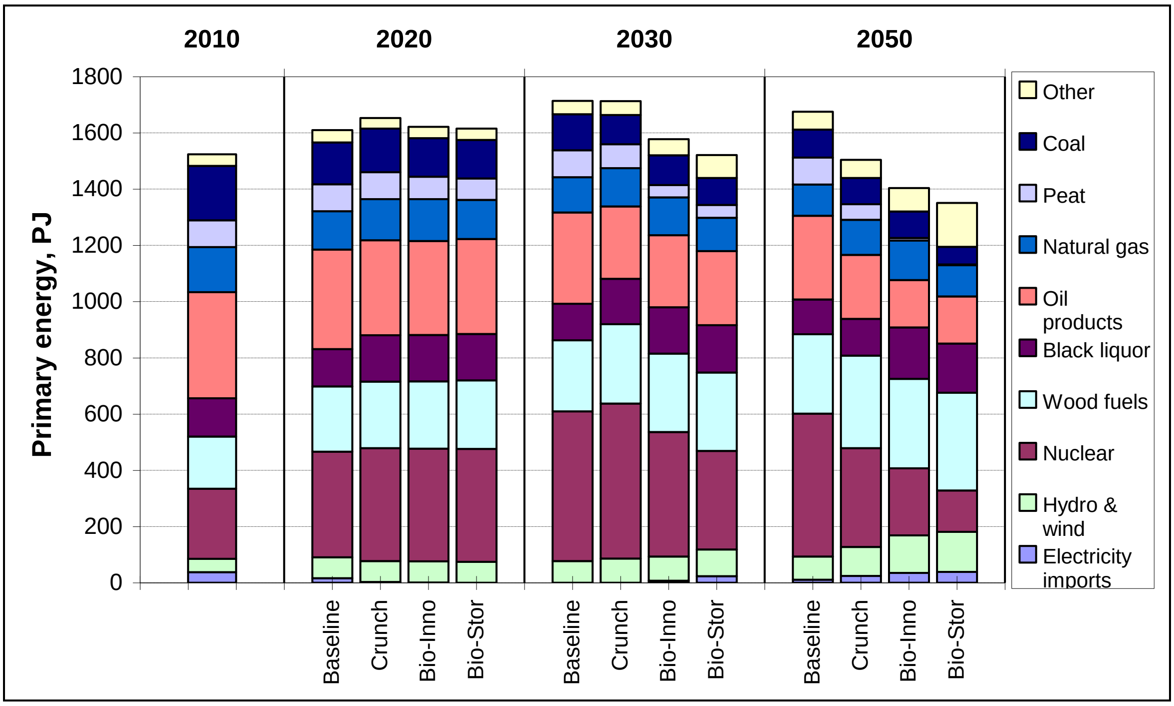

Figure 33. Primary energy supply in Finland.

these scenarios, which tends to increase the computational primary energy. It should be noted, however, that the scenario assessments were completed before the fall 2015, when the negative decision on the Olkiluoto 4 plant was made by the Finnish Government. As a result, the assumptions for the Baseline are too optimistic. Also in the Crunch scenario, one new additional nuclear permit would be required.

In the Bio-Inno and Bio-Stor scenarios the primary energy consumption is close the 2010 level in 2030. After 2030 total primary energy consumption is steadily decreasing, and falls below the 2010 level in each of the Best scenarios, in the Bio-Stor scenario to a level over 10% lower than in 2010.

The contribution of fossil fuels decreases significantly by 2050, dropping at the lowest to around 25% in 2050, while the share of renewable energy increases to 42–65% of total primary energy. The highest contribution of renewable energy is achieved in the Bio-Stor scenario, largely due to the lower overall energy demand and lower level of nuclear energy. Bioenergy remains the most important renewable energy source in Finland in all scenarios, but the growth rates are nonetheless the highest in the use of wind and solar energy.

Figure 34 gives a somewhat more detailed account of the development of renewable primary energy in Finland in the scenarios. As one can see, the level of bioenergy use is almost the same in all the three Best scenarios, despite the differences e.g. in the forest industry production and in the development and deployment of new energy technologies. This indicates that the extent to which increases in bioenergy use are competitive with other alternatives is not very sensitive to the scenario assumptions.

Wood-based biomass is utilized in total about 440 PJ in 2030, while in 2010 the amount was 320 PJ. The increase of 120 PJ is considerably large, but about 30 PJ of it comes from the

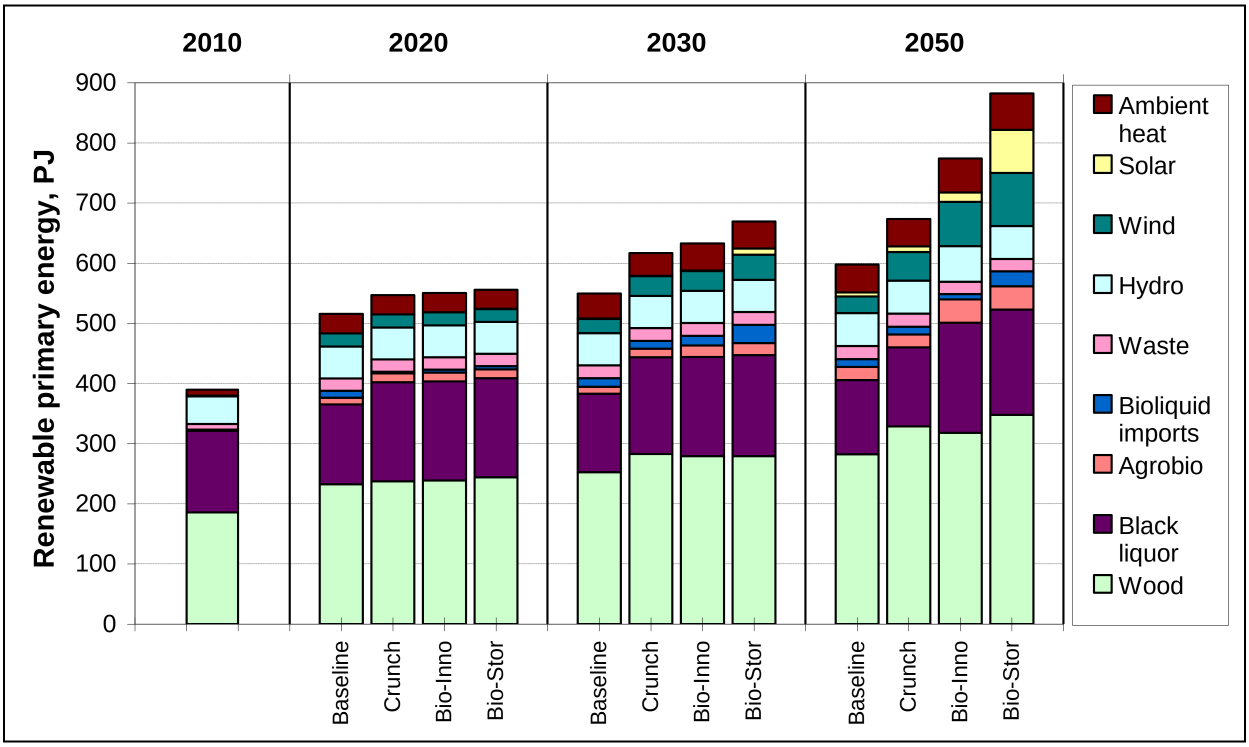

Figure 34. Supply of renewable primary energy in Finland.

increased yield of black liquor from chemical pulping. The remaining 90 PJ is mainly forest residues from final fellings and silvicultural thinnings, and to a small extent from imports. The results indicate that it is economical to utilize most of the available forest residue potential in all three scenarios. Agrobiomass (energy crops and residues) has only a marginal role in the results until 2030. However, after 2030 the tightening GHG policies increase the total level of agrobiomass use to about 40 PJ in 2050.

Hydro power energy remains almost at the present level in the scenarios until 2030, but by 2050 small-scale mini hydro projects appears to become more competitive in the Bio-Inno scenario, leading to a further 10% increase between 2030 and 2050. Wind power increases roughly according to the policy targets until 2030, but become even more competitive after 2030. In the Finnish conditions, solar power appears to remain a rather marginal electricity generation option until 2030, unless the steep cost reductions in the past years continue and new low cost solutions for energy storage would be implemented. As a result, only in the Bio-Stor scenario solar power reaches a 1% share of primary energy by 2030. Ambient heat appears also to have a considerable potential in Finland, and reaches over 40 PJ in 2030 in the global climate policy scenarios.

The development of the overall electricity supply is illustrated in Figure 35. In the Baseline and Crunch scenarios the total supply increases to about 100 TWh in 2030, but in the Bio-Inno and Bio-Stor scenarios the domestic demand for electricity remains at about 90 TWh.

The results clearly illustrate that when moving towards a low carbon society, as in the Bio-Inno and Bio-Stor scenarios, electricity generation should gradually become more or less fully free of GHG emissions. However, this requirement may also have an undesirable side-effect in Finland, causing some shrinking in the economic potential for CHP and district heating. At first, that may seem unexpected in view of the high efficiency of CHP generation. However, because basically all thermal generation should be based either on biofuels,

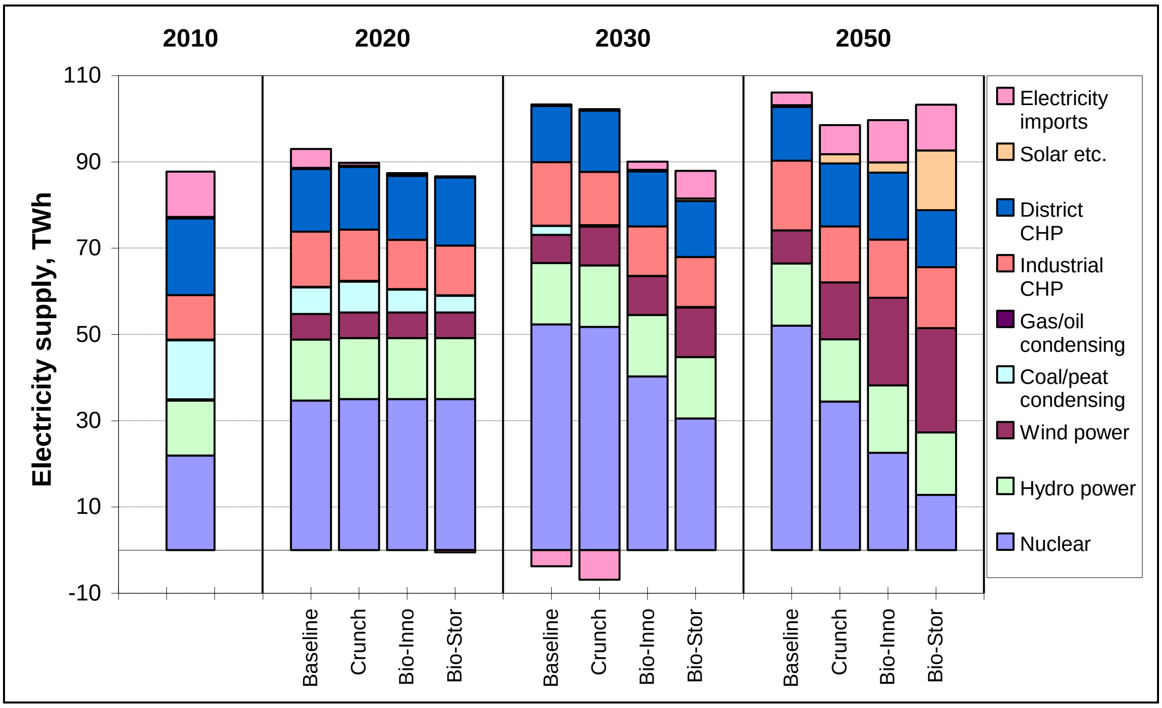

Figure 35. Development of electricity supply in Finland.

carbon-free synthetic fuels, or CCS, maintaining a very high share of CHP generation may become both logistically difficult and uneconomical. This impact is shown in the district CHP generation remaining below the 2010 level in all scenarios until 2050. However, due to the assumed small increases in the output of forest industries and higher power-to-heat ratios, the results show some increase in industrial CHP generation, which may in part serve also community heating demands. In the longer term, the results indicate that CCS may become competitive also in CHP plants producing district heat for large urban areas, especially combined with oxyfuel combustion technology, as it enables maintaining high total energy efficiency in CHP generation. This is realised in the Bio-Inno scenario, where CHP competitiveness in the metropolitan area is improved by investing into a large multi-fuel oxyfuel plant with CCS, using biomass as its main fuel.

Even though the TIMES-VTT results show decreasing market shares of CHP and district heating more detailed analysis would be required in order to take better into account local and regional circumstances on local fuel and energy supply, community structure, and occupation. Also, new technology solutions, like renewable hybrids with district heating, could enter into the markets and enhance the competitiveness of future CHP.

The impacts of continued electrification, which are pronounced in the scenarios with global climate policies, are also visible in the longer-term results of electricity generation. Due to electrification, total electricity demand returns to a clearly increasing trend after 2030 in the Bio-Inno and Bio-Stor scenarios. The impacts are most prominent in the transport sector.

Figure 36 gives a more transparent summary on renewable electricity generation. With respect to the variable renewable generation options, the Bio-Stor scenario exhibits the highest penetration of solar power, 14 TWh, which may be realistic only under the optimistic assumptions concerning energy storage technologies in this scenario, especially given that also wind power has a very high market share of 23% in this scenario. However, in 2030 solar power still accounts only for 0.5 TWh of the total electricity supply even in the Bio-Stor scenario, while wind power does reach over 10 TWh already in 2030 in this scenario. The low competitiveness of solar power in Finland in Best scenarios until 2030 is, in fact, partly explained by wind power remaining a more competitive option for increasing renewable power generation in the Finnish conditions, especially while being subsidised until the national renewable energy targets are met. However, the cost reduction of PV systems has been extremely fast during the recent years and it is very challenging to forecast future cost development. In the Crunch and Bio-Inno scenarios, the new nuclear power plants also tend to limit the room for further investments in renewable generation. Of course, compared to wind power also the long and dark winters make solar power in Finland considerably less cost effective than in many other countries.

Concerning bioenergy-based power generation, the 2020 levels are mostly a result from the EU 2020 policies and the corresponding national renewable energy targets[3]. The results do not show any dramatic further increases between 2020 and 2030; they are only 11–27% in bioenergy generation in the 10 years' time. That is largely resulting from the competing demand of bioenergy in bio-refineries producing liquid or gaseous biofuels. The growth continues to be relatively slow until 2050, and results in all the three scenarios converging to

[3] According to the Finland's national renewable target the share of renewables from final energy consumption should be 38% by 2020.

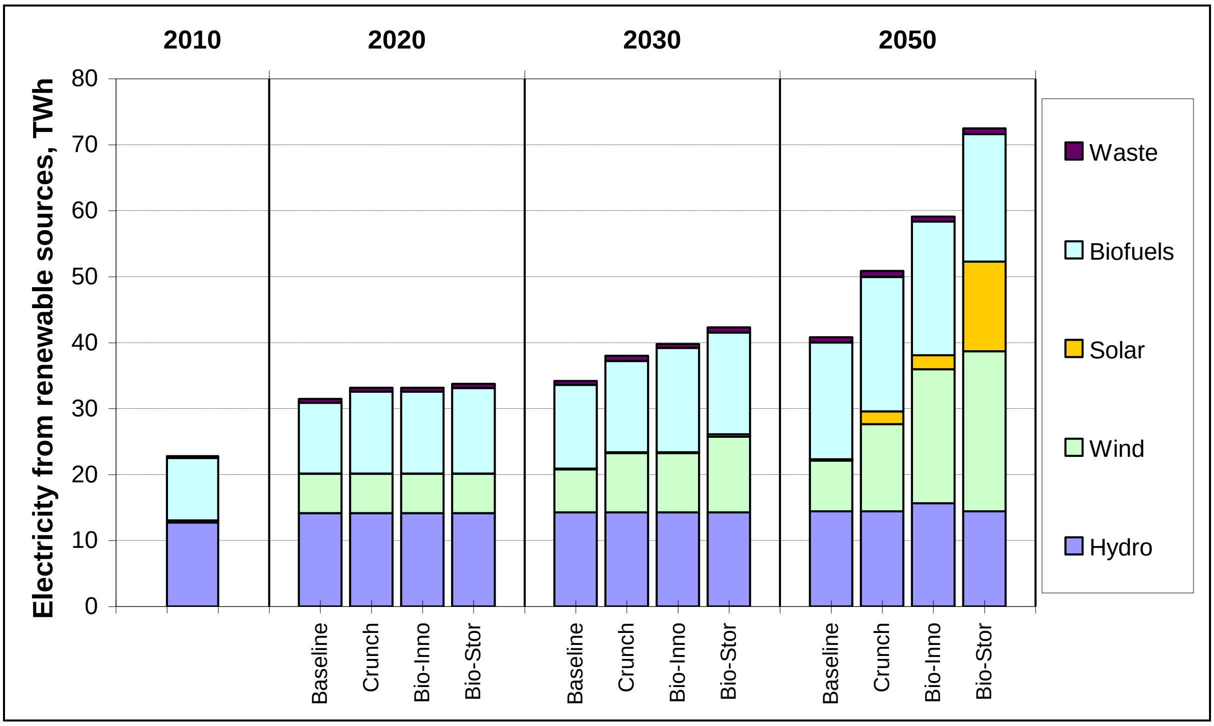

Figure 36. Electricity generation from renewable energy in Finland.

the level of about 20 TWh in bio-power production. In this respect the scenarios appear surprisingly similar to each other. In addition to FBC, gasification combined-cycle plants and oxyfuel technologies, in 2050 also modular solid-oxide integrated gasification fuel cell plants reach a competitive position and offer a flexible small-scale biomass generation option. However, as discussed above, there are large uncertainties related to the cost development and deployment of these oxyfuel and fuel cell technologies especially with the BECCS.

When the electricity system is mostly based on thermal plants, the unit commitment and dispatching of plants can be usually well optimized according to the need for electricity supply capacity. The total capacity needed in the system follows in such cases quite well the peak load, added with a sufficient reserve margins. In Finland the total maximum generating capacity was 16740 MW at the end of 2010. The peak load was 14965 in the 2010–2011 peak load period, and the annual demand was 87.7 TWh. However, the simultaneously available capacity of power plants during the peak was only 13100 MW, and the residual load primarily covered by imports can be estimated at about 1900 MW. The total capacity needed in 2010 can thus be roughly estimated at 18600 MW, as shown in Figure 37. While the average peak utilization time was thus 5860 hours for the peak load, the total utilization factor was only 4720 hours.

In the energy system model, both the available capacity at peak time and reserve capacity requirements have been modelled on the basis of technology characteristics and historical statistics. The resulting development of the total maximum generating capacity and the utilized import capacity during the peak are shown in Figure 37. As one can see, the expansion of variable electricity generation has a strong impact on the total amount of capacity required. Already by 2020 more capacity is required in the system, but the impacts are much more pronounced in the longer term. According to the model results, in 2050 the total capacity needed in the Finnish system would be 25–35 GW, depending on the scenario.

The highest capacity requirements appear in the Bio-Stor scenario, where the large solar power capacity has practically no contribution to the peak load. However, the mitigation factor in this scenario is the introduction of additional energy storage in the system, which can be effectively used for balancing the short-term variations in the demand.

One of the characteristics of the Finnish energy system is the use of biomass for large-scale energy conversion, currently mainly within the pulp and paper industry and in public power and heat generation, but in the future also in bio-refinery plants producing liquid biofuels. Utilizing the substantial forest biomass resources also opens up the possibilities for negative emissions via BECCS, thereby facilitating deeper cuts in overall emissions.

The distribution of bioenergy consumption into the main utilization sectors is illustrated in Figure 38. As one can see, bioenergy use in the power and heat generation sector increases steadily in all scenarios. At the highest, the consumption is approximately doubled in 2050 compared to the 2010 level. In the scenarios with global climate policies, most of the increase occurs already by 2030, and after that the growth in power and heat generation remains very modest. That can be explained by the large expansion in variable renewable generation after 2030, which directs most of the increase in bioenergy use in other sectors than energy production, like transport. In addition, bioenergy productions potentials are being already close to fully utilized in Finland by 2050.

The level of bioenergy use in the industry sectors remains quite stable in the scenarios. In all of the three Best scenarios, the consumption in 2030 is about 20% higher than in 2010. By 2050, industrial bioenergy use declines 10% in the Crunch and Bio-Stor scenarios, but increases further 12% in the Bio-Inno scenario, due to the assumed highest production volumes in the forest industries.

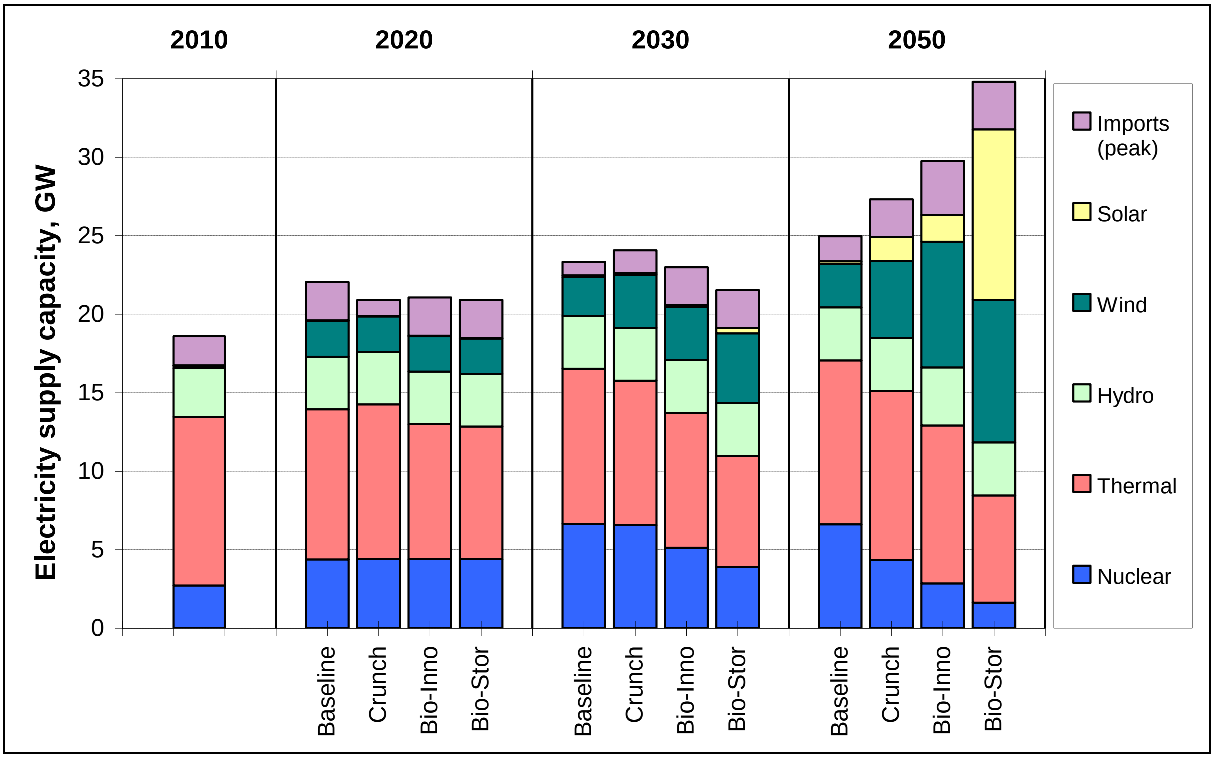

Figure 37. Development of electricity supply capacity in Finland. Imports refer to the utilized capacity during the peak.

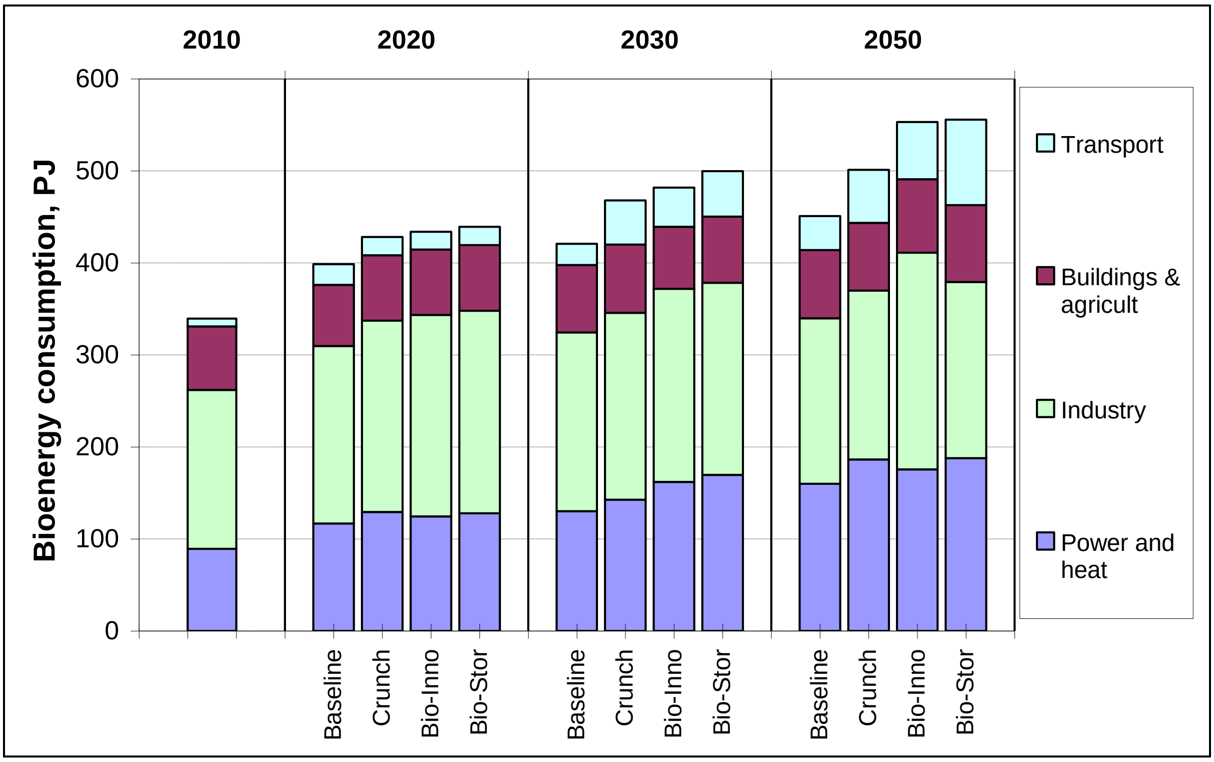

Figure 38. Bioenergy use by sector in Finland (includes fuels for main activity producer power and heat plants as well as industrial power production).

Concerning the transport sector, the scenario results indicate that along with second generation liquid bio-fuels and electrification in the longer term, the obstacles to achieving deep emission cuts will be much reduced even in this sector. In all scenarios, the amount of transport biofuels reaches over 40 PJ in 2030. The similarity in the amount is explained by the EU 2030 policies for non-ETS sector assumed in force in all scenarios.

However, in 2050 the largest amounts of liquid biofuels are needed in the Bio-Stor scenario, where electric vehicles were assumed to have a lower penetration rate than in the Bio-Inno scenario. The differences are clearly seen in Figure 39, which illustrates the balance between the production and demand for transport bioliquids in Finland.

Even though the net imports of transport biofuels rises in some cases up to 15 PJ per annum, domestic production becomes significant in all the scenarios. Moreover, after 2030 the largest bio-refineries would be equipped with carbon capture. The highest consumption levels are in the Bio-Stor scenario, where biofuel production is also utilized as a means of long-term energy storage. According to the scenario assumptions, electrification of passenger transports becomes most dominant by in the Bio-Inno scenario, pushing the market share of liquid biofuels in the passenger car fuel market into a downward turn after 2040. However, as biofuels are the main option for reducing emissions in heavy transports and aviation, the level of biofuel demand still grows significantly between 2030 and 2050. Only the Bio-Inno scenario has a positive trade balance in liquid biofuels after 2020.

As mentioned above, the large biomass resources and the advanced bio-refinery technologies make CCS a viable option in large biofuel production plants. According to the results, BECCS would, in fact, account for the majority of the CCS potential in Finland, and it appears to be a particularly attractive option in bio-refinery plants, where carbon can be captured from an almost pure CO_2 stream. On the other hand, the economic potential for CCS in fossil fuel based energy production appears to be limited, and is mostly related to large multi-fuel CHP plants using also biomass, as well as hydrogen production. Within industry, the most promising CCS option appears to be enhanced blast furnace process with top gas recycling and oxygen injection.

The development of the Finnish greenhouse gas emissions is depicted in Figure 40. According to the results, the national target of an 80% reduction in GHG emissions by 2050 is not fully achieved in either the Bio-Inno or the Bio-Stor scenario, which both had the same target set for the total European emissions. This result indicates that such deep emission reductions are in Finland somewhat more costly than in Europe as a whole. However, the 78% reductions in the Bio-Inno scenario are quite close to reaching the national target.

Of the main sectors causing GHG emissions, agriculture turns turn out to be the one where achieving substantial reductions is the most difficult. The majority of the emissions in this sector are methane and N_2O emissions not directly related to energy use. The second most difficult main sector is industry, and in particular, process-related emissions from basic metals, basic chemicals and minerals manufacturing, for which new low-emission processes are technically or economically difficult to implement. Consequently, even larger reductions than the overall target would be needed in other sectors. It is thus obvious that without achieving higher cuts or even negative emissions in some systems, such as BECCS applications, reaching very strict overall targets may become costly for the economy.

As practically no suitable geological CO_2 storage capacity has been identified within the territory of Finland, the transportation and storage related to CCS applications in Finland have been estimated by assuming that the storage site is located either in the North Sea or

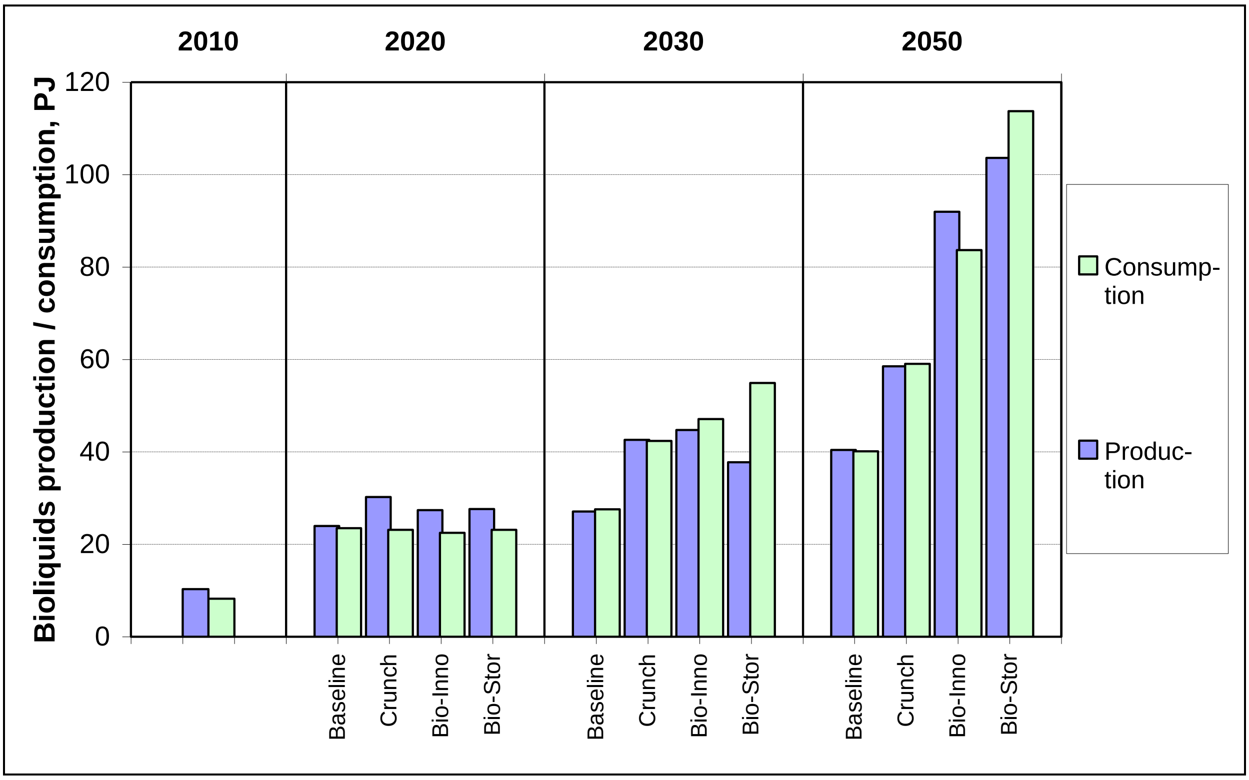

Figure 39. Demand and production of liquid biofuels in Finland.

the Barents Sea (Teir & al. 2010), and in the Bio-Stor scenario both the CO_2 transportation and storage costs were assumed higher than the base estimates. Despite the considerable additional costs involved, the results indicate that CCS could still have a notable role in Finland, if only the storage technology will be commercialized on a wide scale. That was assumed to take place most favourably in the Bio-Inno scenario, which also shows the highest proportions of emission reductions occurring within the emission trading sectors.

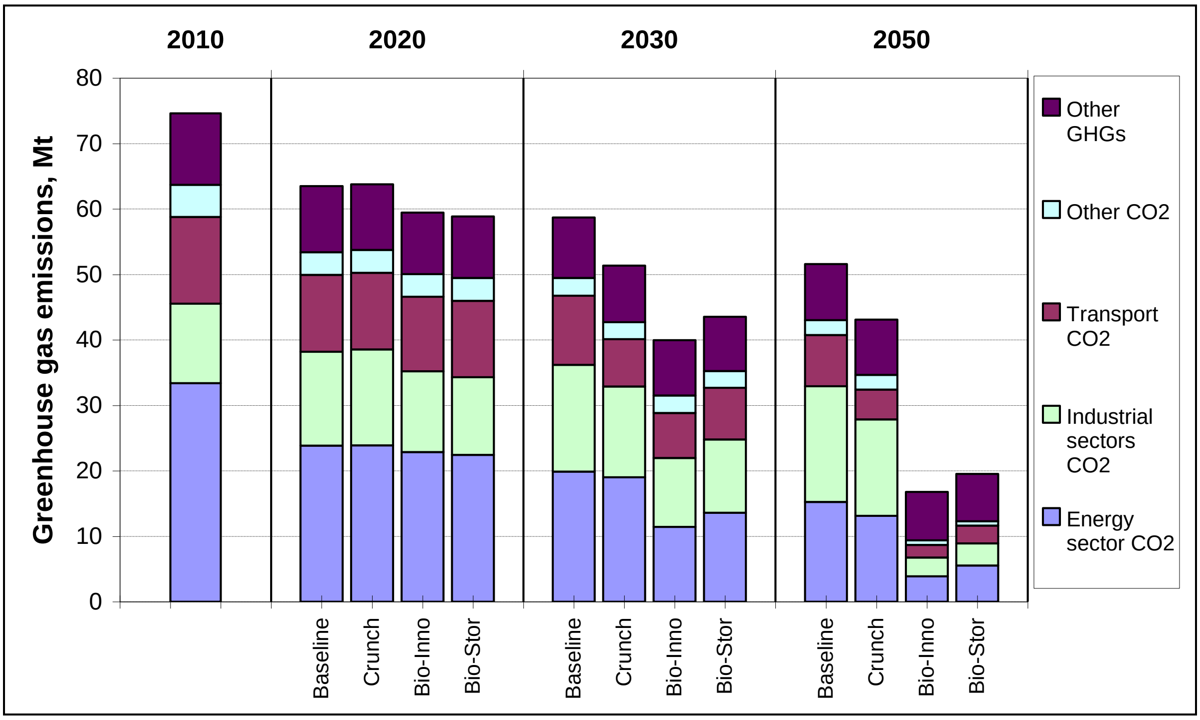

Figure 40. Development of greenhouse gas emissions in Finland.

7.4 Results for emerging Asia

China and India are considered to be the largest emerging economies, which have a crucial impact on the world economy and also energy technology markets. Therefore, we present the main results also for these two countries combined, and use the acronym ECI for Emerging China and India.

The development of the total primary energy consumption in ECI is illustrated in Figure 41. In 2010 the region already accounted for about 25% of global primary energy. Fossil fuels are the main source of primary energy, about 85%. The use of bioenergy is also extensive, but it consists mostly of traditional biomass. Bioenergy accounted for about 12% of primary energy in 2010, i.e. in proportion about twice as much as in Europe, and in absolute terms over three times as much. Nuclear and hydro power covered together only 3%.

Coal is by far the largest energy source in ECI, both at present and at least in the next few decades. It accounts for 60% of the primary energy in 2010, and according to the results, the contribution would still be at least 45% in 2030, if not higher. And because the economies have a high growth, in absolute terms the use of coal is either increasing, or at best remaining roughly at the current levels. Utilization of all main sources of renewable energy is increasing rapidly, and according to the scenario results will account 22–26% of the total primary in 2030. The use of wind and solar energy are growing most rapidly, but bioenergy use would also increase by 33–62% between 2010 and 2030.

Nuclear energy still has a very minor role in ECI, but cording to some projections it could become one of the main energy sources in both China and India. In the Best scenarios, nuclear power capacity does increase up to about 150 GW in by 2030, which is about 40% of the global capacity in 2014. However, larger investments take place only after 2030.

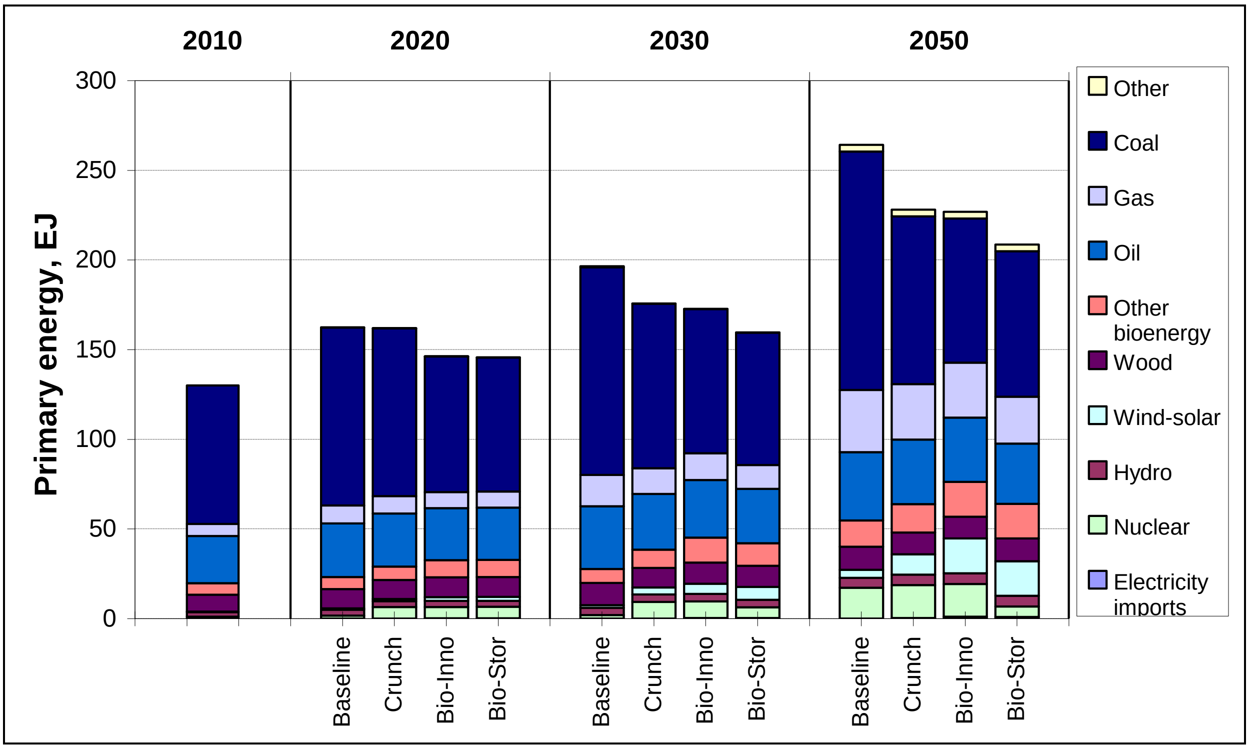

Figure 41. Primary energy supply in China and India.

Bioenergy is thus far the main source of renewable energy in China and India, and hydro power is also important, especially in China. In the use of wind and solar energy the countries are still at very low levels compared with the use of other energy sources but the growth rates have been remarkable in recent years. However, because of the huge amounts of traditional bioenergy used in the residential and agricultural sectors, the high increases that occur mostly in modern energy uses do not change the overall primary energy balance very quickly.

The results indicate that by 2030 the total renewable energy supply can almost double in the ECI region, and the most important contributions come from agrobiomass, at most about 7 EJ, and from solar and wind energy, both about 3.5 EJ each. Wood biomass appears to be already close to the limits of sustainable use, and therefore the potential for increasing its use is rather small. According to the results, the increase in the use of wood for energy is at most 2.4 EJ by 2030. In total the use of bioenergy increases the most in the Bio-Inno scenario, about 9.5 EJ, which is a huge amount, and requires very large investments both into the primary production and conversion technologies. The ECI region would thus be a good market for the European bioenergy technology, which was assumed to be the global leader in the Bio-Inno scenario.

When looking beyond 2030, the results indicate steep growth in solar energy use by 2050 in the ECI region, highly surpassing the growth rates of wind power. At the same time, however, also the use of energy crops and agricultural residues would continue to grow with high rates. The emerging economies would become among the leading users of both solar energy and modern bioenergy. Due to the global climate policies with roughly equal emission targets, the differences between the Bio-Inno and Bio-Stor scenarios appear to be diminishing by 2050, as one can see from Figure 42.

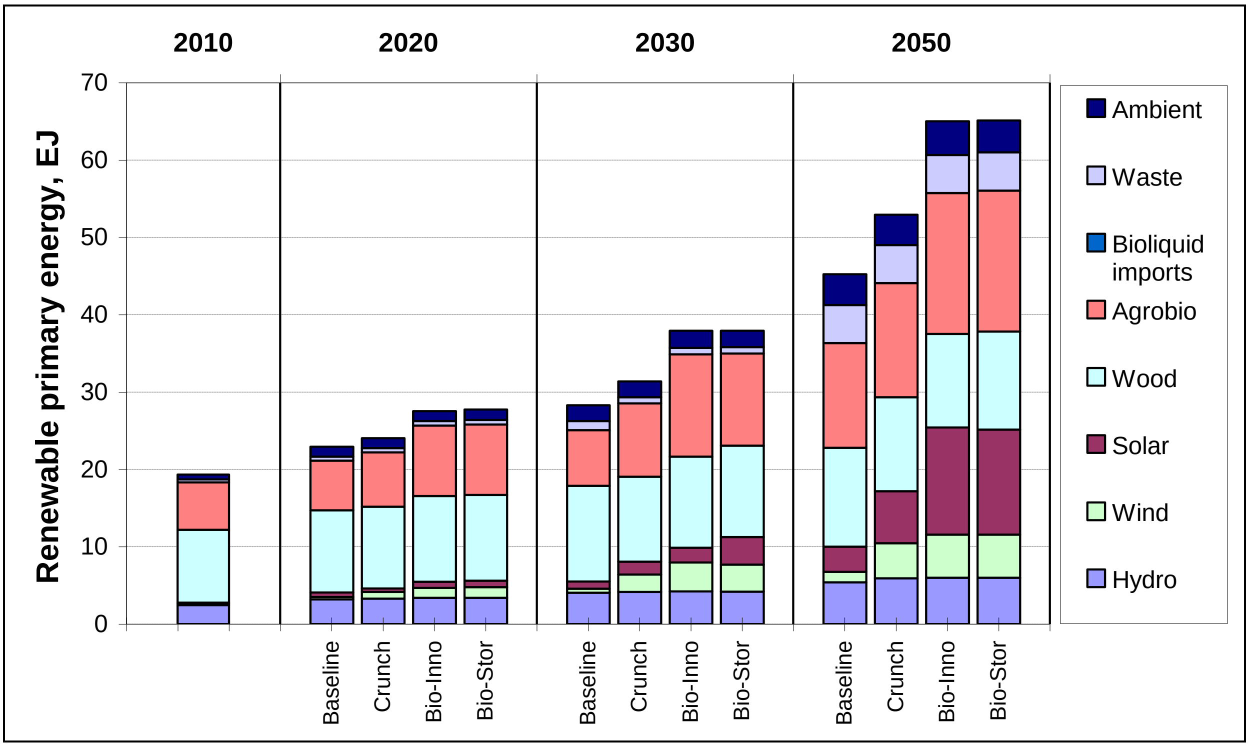

Figure 42. Supply of renewable primary energy in China and India.

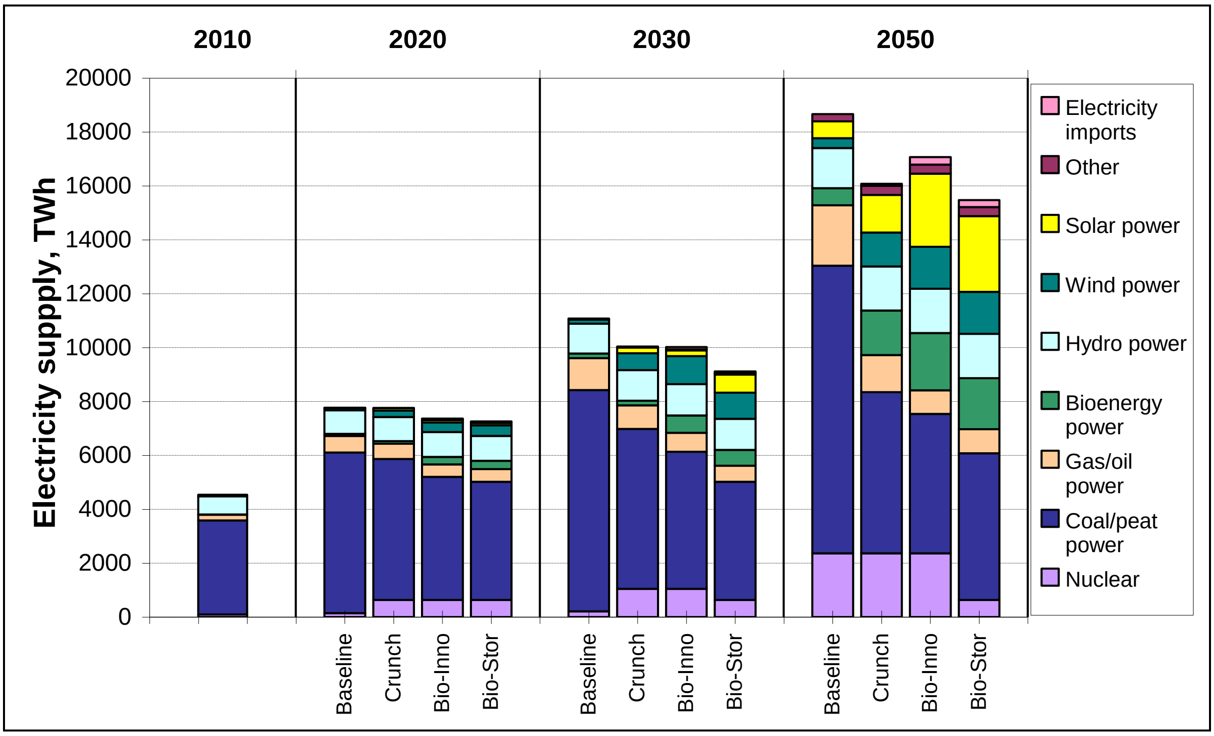

Figure 43. Total electricity supply in China and India.

In terms of primary energy the growth in the energy consumption of the rapidly growing emerging economies appear perhaps even surprisingly modest. However, one should bear in mind that the structure of these economies is inevitably changing considerably in the coming decades. Heavy, energy intensive basic industries are no longer expected to show such high growth rates in the long term, and therefore total energy consumption is expected to increase much less than the total volume of the GDP. At the same time, energy consumption is shifting towards electricity, which causes higher growth rates in the electricity demand, as illustrated by the total electricity supply depicted in Figure 43.

The total demand for electricity is more than doubling in all scenarios between 2010 and 2030, and almost a further doubling occurs between 2030 and 2050. At the end of the time horizon, the ECI region would thus consume electricity nearly as much the whole world consumed in 2010. In terms of per capita consumption, China and India would reach about one-third the level in Finland by 2050, largely due to their extensive manufacturing industries. Such high growth in just a few decades requires vast investments, and therefore the cost of capital and the capital-intensiveness of competing technology alternatives will probably become an increasingly important factor directing the energy investments.

In the Baseline, the electricity supply of China and India would continue to be heavily dependent on coal plants. And until 2020 the results do not show any significant changes in the structure of the overall supply. By 2030, wind power and nuclear power would already have a notable contribution to the supply. Bioenergy would reach a 7% share of the electricity market in both in the Bio-Inno and Bio-Stor scenarios, and solar power reaches a comparable share in the Bio-Stor scenario. However, in view of the rapid developments in recent years, the results for solar power might be underestimating its economic potential in these rapidly developing countries. Nonetheless, the results do indicate a much larger economic potential for both solar and wind power by 2050, in particular in the scenarios with global climate policies. Interestingly, the competitive position of bioenergy in power production seems to be almost equally good in all three Best scenarios in 2050.

A more detailed account on power generation from renewable energy sources is given in Figure 44. As clearly seen from the Figure, China and India are still at very low levels with respect to modern use of renewable energy for electricity generation, even though the growth rates have been remarkable during the recent years.

While the total electricity demand is at least doubling by 2030 in the scenarios, the growth in renewable electricity generation is much higher. In the Crunch scenario it increases three-fold, and in the Bio-Inno and Bio-Stor scenarios it increases four-fold compared to 2010. And, when one takes into account that 90% of the renewable electricity came from hydro power in 2010, the growths for the other renewables are still many times higher.

Bioenergy-based power production was only 11 TWh in 2010, but in 2030 it grows to 650 TWh in the Bio-Inno scenario and to 590 TWh in the Bio-Stor scenario. Consequently, even though the role of bioenergy seems quite small in the overall electricity supply, the market opportunities for bioenergy power plant technology appear to be very large in these countries in the next decades, and would fit reasonably well both with the assumptions of European leadership in bioenergy innovations in the Bio-Inno scenario and the emerging economies driving the technology development in the Bio-Stor scenario.

Moreover, by obtaining a good foothold in the market in the short term could well open up yet much larger opportunities in the subsequent decades. By 2050 the bioenergy-based power generation may expand up to the level of 2000 TWh, as suggested by the results in the Bio-Inno scenario. The longer-term results appear also more robust for bioenergy than those for 2030, indicating a good competitive position for bioenergy even when very large amounts of solar and wind power are introduced into the supply systems.

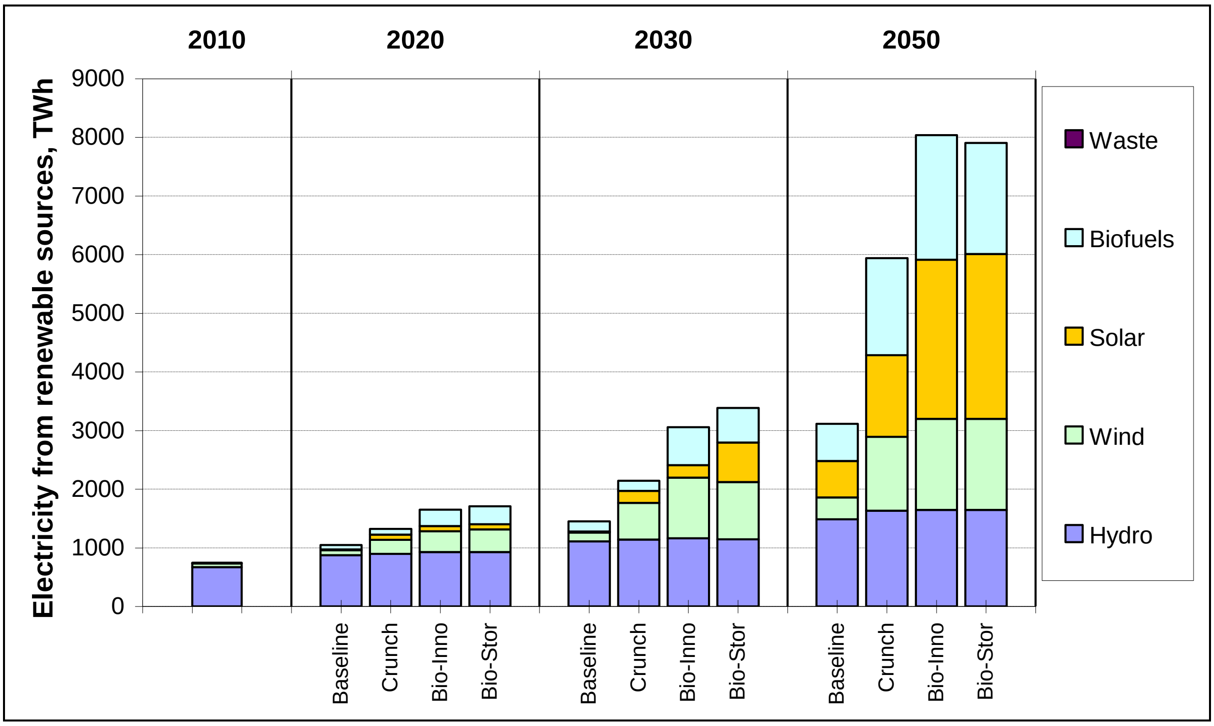

Figure 44. Electricity generation from renewable energy in China and India.

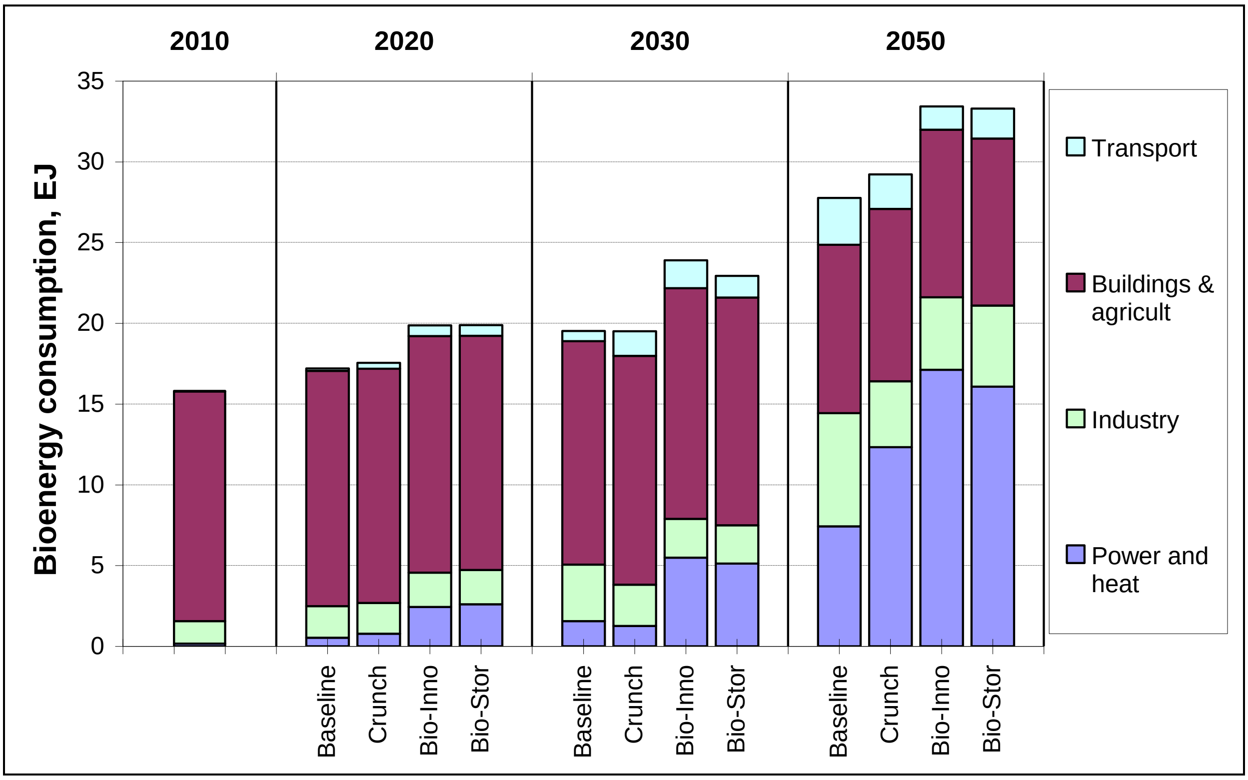

Figure 45. Bioenergy use by sector in China and India.

When looking at bioenergy on the consumption side, the most significant change in the emerging economies is related to the break-through of modern biomass use. While in 2010 about 90% of the bioenergy was still used in the residential and agricultural sectors, already by 2030 the share might drop to the level of 60%. Nevertheless, in the energy systems model the changes in the fuel mix of the residential sector were allowed to occur rather slowly, and therefore even faster changes might be possible, as one can deduce from Figure 45. On the other hand due to increasing energy demand the traditional biomass uses may also increase still over the next decades. But anyway, by 2050 the results show clearly lower levels of biomass consumption in the residential, commercial and agriculture sectors.

With respect to climate change mitigation, the transport sector is among the most difficult sectors to achieve deep emission reductions, and therefore the transport biofuel markets are focused on the countries with tightest climate policy targets, as in Europe. According to the results, in China and India the role of liquid biofuels in transport would, indeed, be much smaller than in Europe or the USA. In 2030, only less than 10% of all bioenergy use in China and India would be consumed in the transport sector, and the proportion would not significantly rise by 2050. Any bio-refineries in these countries would thus be mostly export-oriented according to the scenario results, and for that part the consumption is not included in Figure 45.

On the basis of the results, the biggest expansion in bioenergy use is thus expected to occur in power and heat production, both for communities and industry. In the Crunch scenario the expansion is remains moderate until 2030, as already mentioned above, but in the other two scenarios it is very large even in the short term. In the longer term, bioenergy-based power generation has strong growth potential in all the scenarios.

The increasing energy demand in the rapidly growing developing countries represents one of the greatest challenges to the mitigation of climate change. As shown in the previous results, fossil fuels are the main energy source in the emerging economies, and unless great changes take place in the energy systems, greenhouse gas emissions will be increasing.

The development of the greenhouse gas emissions in China and India is illustrated in Figure 46. The Baseline scenario clearly shows the importance of these two countries in the future greenhouse gas balance. Without global climate policies or national measures implemented for emissions abatement, the total greenhouse gas emissions from China and India would reach over 20 Gt (CO2 eq.) by 2050, while the 2 °C target would require cutting the missions clearly below the 2010 level by 2050. One should note that the global policies assumed in the Bio-Inno and Bio-Stor scenarios were deliberately set to aim at a somewhat less ambitious target, corresponding to a maximum temperature change around 2.5°C. Therefore, the gap between the Baseline and the 2 °C target would be still higher.

In the Best scenarios, the energy sector emissions could be kept below the 2010 level in 2030, and thereafter substantial further reductions are possible in the Bio-Inno and Bio-Stor scenarios by 2050. In the Bio-Inno and Bio-Stor scenarios CCS would enter the market also in China and India, mostly in large fossil fuel fired power plants.

The industry sector development appears to be quite crucial for the long-term emissions abatement, as the emissions tend to more than double by 2050, and appear to be much more difficult to reduce than the energy sector emissions under the global climate policies. High cost emission reductions in the industrial sector would also reduce the competitive position of the emerging economies in favour of the old industrialized countries like Europe. However, as seen in the scenario results, deep cuts in the industry sector emissions remain pending in 2050.

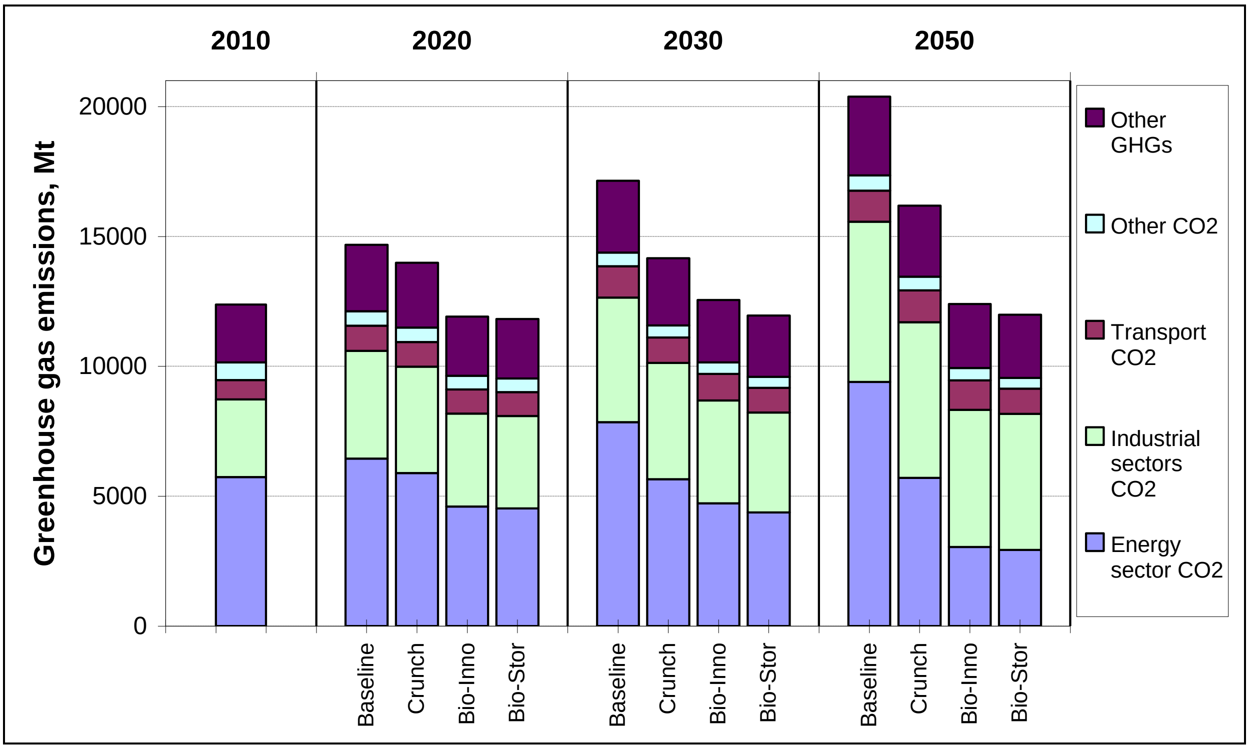

Figure 46. Greenhouse gas emissions in China and India.

7.5 Discussion

At present, most of the global bioenergy is still consumed in traditional small scale uses. About two thirds of the global demand for biomass for energy was in 2010 used in the residential, commercial and agriculture sectors for heating and cooking. However, in the future this picture is expected to change radically. According to the analysis made here, the total bioenergy use could double to over 100 EJ between 2010-2030, and about one third of that amount could be utilized for power and heat production in the energy sector and industry. The largest utilization level is reached in the Bio-Inno scenario, where Europe is in the forefront of bioenergy technology development, but the Bio-Stor scenario is not left much behind despite having a higher penetration of other renewables. The overall results are in a good agreement with a number of other estimates concerning bioenergy potentials and demand projections (e.g. IPCC 2012, IRENA 2014) and are not among the highest bioenergy projections.

When going beyond 2030, the analysis indicates that global bioenergy demand could again nearly double between 2030 and 2050, reaching up to 180 EJ in the scenarios with global climate policies. That would correspond to about 90% of the estimated global potential being taken into use. More than half of the total increase would be used for producing liquid biofuels, mainly for the transport sector. However, the largest contribution to the increase in bioenergy use would come from energy crops, most clearly when moving beyond 2030.

Given the high expansion in bioenergy use, the availability of sustainably produced biomass is obviously a critical concern in the scenarios. Sustainable biomass production should avoid any adverse side effects on food production and greenhouse gas balances due to land-use change. That calls for international agreements on the criteria for sustainable biomass as well as monitoring mechanism to ensure consistency and transparency.

In Europe, total primary energy consumption is on a decreasing trend, but growth can still be expected in electricity demand, particularly under tight climate policies, which tend to boost electrification in all sectors. The results indicate that the production of electricity from bioenergy could almost quadruple by 2030, under the favourable assumptions used in the Bio-Inno scenario. Given the low initial level in 2010, only 3% of total electricity supply, a growth this high might well prove to be feasible.

The potential for increasing bioenergy use in Europe is strongly focused on agrobiomass, i.e. energy crops and agricultural residues. Although the prospects for increasing the use of wood biomass for energy are also notable, over 1 EJ, the additional wood energy potential in Europe is less than 2% of the total primary energy consumption, and is mainly associated to enhancing the recovery of forest residues. For decarbonising the transport sector in Europe, utilization of the agrobiomass potential will thus be crucial, which may raise issues of sustainability. The results from the scenarios show, indeed, quite high increases in energy crop production, but the overall bioenergy results also appear to be in a good agreement with the trends in the national renewable energy projections.

In our scenarios, installing new nuclear generation capacity was allowed, expect in those countries, which have decided to phase out nuclear, like Germany. The scenario results indicate that nuclear power would recover its competitiveness in Europe under tight climate policies, and would be expanded after 2030, if politically accepted. However, that did not seem to have any notable impact on bioenergy utilization in the scenario results.

Finland is at an exceptionally high level in modern use of biomass for energy, which has been strongly tied to the role of forest industries and advanced forest management in Finland. Most of the bioenergy in Finland is produced from forest biomass, both today and in the foreseeable future. Energy crops and agricultural residues have also notable potential in the longer term, but their deployment would take time. By 2030, about 75% of the increase in bioenergy use would still come from forest residues.

The demand for bioenergy in Finland concentrates on power and heat production in the industry and energy sector, which covers about 80% of bioenergy consumption. While Finland is already one of the forerunners of employing combined heat and power for efficient power and heat production, bioenergy would become an increasingly important fuel in community power plants. In fact, under tightening climate policies, the future of wide-scale district CHP generation in Finland appears to be largely dependent on bioenergy supply. On the technology front, the model results indicate that gasification combined-cycle technologies may be expected to be among the key bioenergy technologies for CHP, while in the short term FBC technologies and biomass co-firing options still have a major role. After 2030, it may also turn out to be an attractive option to apply BECCS for large-scale CHP. In addition, in the Bio-Stor scenario SNG production becomes a competitive option of producing biogas into the gas network for use in power and heat production and industry.

According to the results, bioenergy thrives almost equally well in Finland in all of the three scenarios, despite the differences in their assumptions. For the Crunch scenario, the high fossil fuel prices make bioenergy an attractive option. In the Bio-Inno scenario rapid development of bioenergy technologies and BECCS offer new business opportunities both in power and heat production and bio-refineries. Finally, in the Bio-Stor scenario with little new nuclear power anywhere in Europe, the emission prices rise to the highest levels, thereby improving the competitive position of all renewables, and bioenergy based thermal power is needed for counterbalancing the large amounts of variable generation.

Producing biofuels from sustainably produced biomass in bio-refineries equipped with BECCS can be viewed as mitigating climate change in two ways. First, they reduce emissions by replacing fossil fuels, and second, they also create a stream of negative emissions by storing a large part of the organic carbon in a carefully selected geological formation. These negative emissions can offset emissions in other sectors. At best, by increasing bioenergy use one could in this way achieve larger cuts in emissions than by expanding the use of other renewables. The emission reduction impact would perhaps be the highest in BECCS power plants, as there almost all of the carbon content of biomass could be captured. However, the overall economics of BECCS appears to be best in bio-refineries.

The results strongly support the assessment that sustainable bioenergy can be one of the cornerstones of renewable energy supply when moving to a low carbon society. It makes a significant contribution to the doubling of global renewable energy share between 2010 and 2030, which would be very unlikely without the projected increase in bioenergy use. Nonetheless, due to the estimated limits on sustainable bioenergy production, a wide portfolio of renewable energy sources and technologies will be necessary for reaching the policy targets on climate change.

8 Forest sector results

We will discuss the development of the forest sector up to the year 2030. In the tables, we also provide projections to 2050, but they should be taken with high caution: the more distant the future is the less valid the assumptions concerning technologies, new products made of wood and their regional demands are likely to be. For instance, it is likely that the demand of currently known printing and writing papers will continue to decline after 2030 unlike assumed in the projections. However, we refuse to think that no new and novel products would be invented to take their place in the product palette of the forest industry. Calculating the models forward with the technologies, products and demand developments resembling those in 2010-2030 reserves wood resources for these novel products, which compete with energy sector for wood in the future. Although several products were modelled in detail, we comment the developments aggregated to larger product categories due to space limitations and due to focus of this work being rather on biomass demand than on the forest industry.

8.1 Results for Finland

8.1.1 Forest industry production

Figures 47 and 48 present the projected development of forest industry production in Finland for mechanical and chemical forest industry, respectively. The projections follow from the many assumptions made e.g. on the demand for forest products and the production costs including price of wood, which in turn is affected by the supply and total demand of wood. These assumptions define the competitive position of Finland as a producer country with respect to the producers in other countries.

The total production in the mechanical forest industry reaches the level of some 13.5–14 million cubic meters in 2030. The scenarios differ relatively little with respect to the output levels, because the demand for solid wood products is not developing very strongly in the main market areas for Finland. Hence, the production of sawn wood, plywood and other solid wood product is somewhat stagnant in all the scenarios, yet higher than today. Production of particle board, OSB (oriented strand board), MDF (medium-density fiberboard), and other panel products is not very important branch in Finland currently. Their production gains increasing ground, however, in the scenario Bio-Stor. This is due to the fact that competition over biomass between the panel producers and energy sector tightens more in the other parts of the world than in Finland.

The production of printing and writing papers decreases to the level of some 4.3 Mt in 2030, with the exception of the scenario Crunch with lower production costs. While not quantified in the input, this result could also follow from the consideration that the economies are growing more slowly in the scenario Crunch than in the other scenarios. Therefore information technology replacing printing and writing papers could be thought of being developed and adapted more slowly in the scenario Crunch. In is notable that the decline of the per capita demand for these products was assumed to halt by 2030, which may be unrealistic. Nevertheless, we consider that after 2030, these products are more and more considered to proxy other, new, yet unknown paper and paperboard products, which will step on the production portfolio of the forest industry companies in the coming decades. So, the production figures for printing and writing papers in the last two decades projected should be partly interpreted to represent such other, novel products.

There is a slight increase in paperboard production in all the scenarios in Finland. New investments in production capacity are seen first, followed later by some closures of older machines. This makes production peak before 2030.

In the scenario Bio-Inno, the increase in the production of dissolving pulp and innovative fiber products in Finland (+1.3 Mt in 2030) slows the increase in sulfate pulp production. Sulfate pulp production sets to the level of some 7.6 Mt in 2030, after first raising to a considerable higher level in 2020. An increasing share of the pulp supply goes to the export market. The production of all chemical pulp totals almost 9 Mt in 2030. In the scenario Crunch, the total production of chemical pulp increases to 8.5 Mt in 2030, the amount being largely (8.1 Mt) traditional sulfate pulp. In the scenario Bio-Stor, the total pulp output is a bit higher than in Crunch (8.3 Mt in 2030), with the supply of both dissolving and sulfate pulp grades increasing.

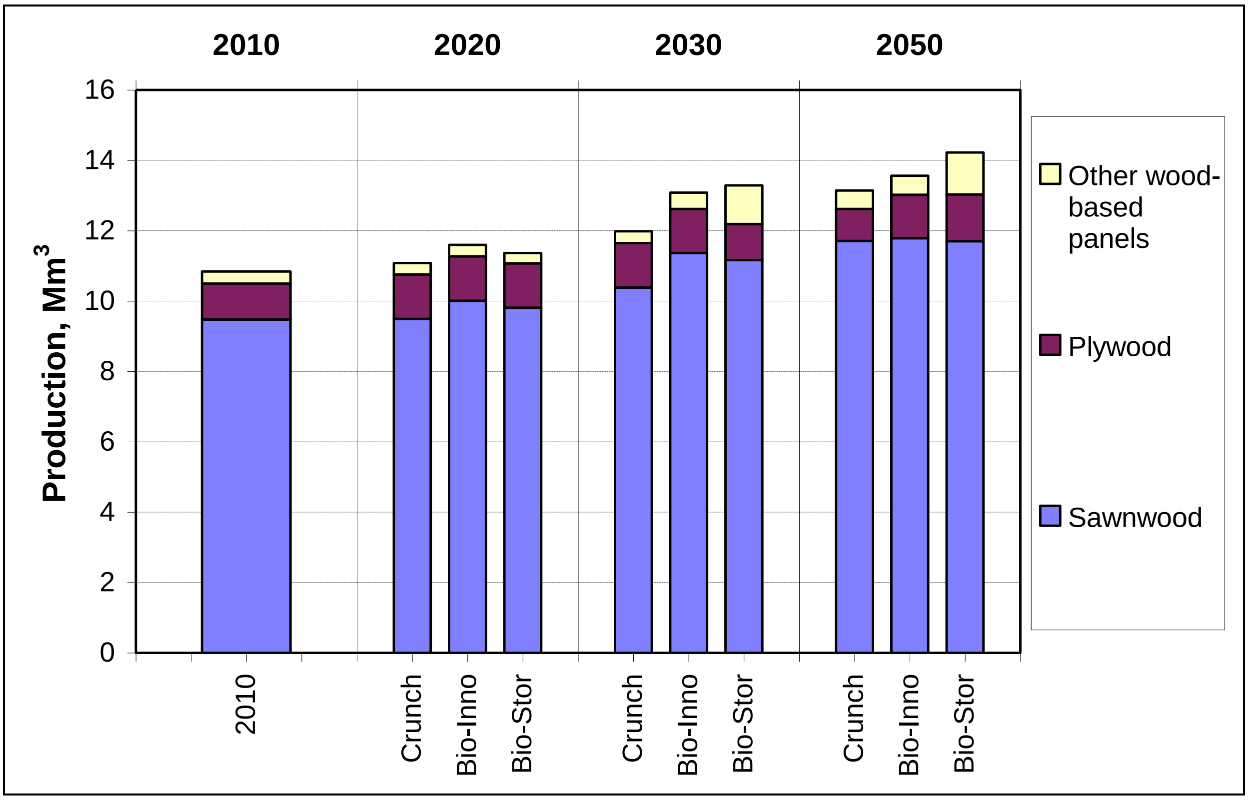

Figure 47. Production of mechanical wood products in Finland, millions m³

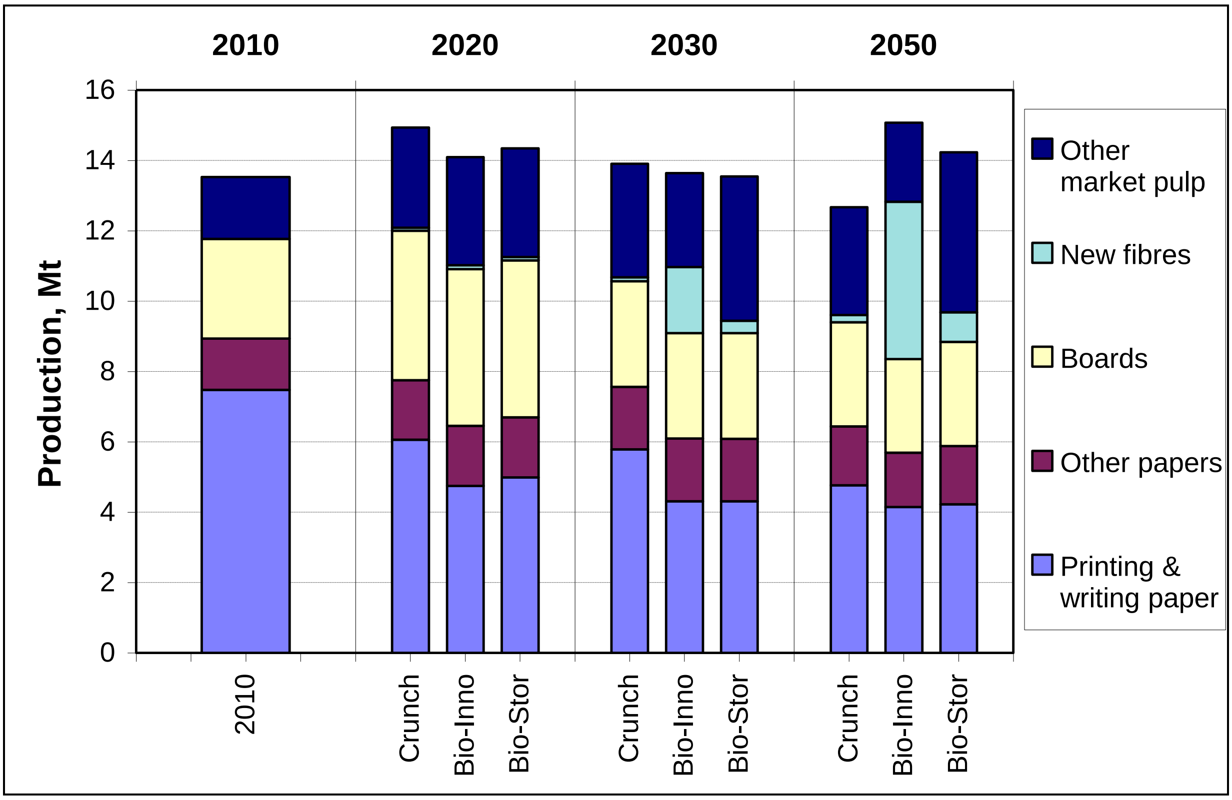

Figure 48. Production of printing and writing papers, paperboard for packaging (boards), other paper and paperboard and market pulps in Finland, millions tonnes.

8.1.2 Roundwood harvests

In all three scenarios, the relative increase in harvests is higher in Finland than in the EU on the average (Table 6). Measured over bark, the total round wood harvests in Finland increases by 9 (17%, Crunch) – 15 Mm^3 (28%, Bio-Stor) during 2010–2030. The round wood harvests in 2030 vary between 61 – 67 Mm^3 across the scenarios. These figures are clearly below the projected economically and ecologically sustainable annual cutting potential for roundwood which is roughly 78 Mm^3 during 2020-2040 (Natural Resources Institute Finland 2015).

In the scenarios Bio-Stor and Bio-Inno, coniferous sawlog harvests grow by about 6 Mm^3, while pulpwood harvests increase by about 8 Mm^3 up to 2030. In the scenario Crunch, the respective growth figures are around 3 Mm^3 and 6 Mm^3. There the growth in pulpwood demand is rather low in comparison to the growing supply potential. Consequently, the mill prices remain close to 2010 levels also in 2030. Instead, in the other two scenarios, the mill prices of softwood pulpwood may be at 20% higher level in 2030 than in 2010.

Harvests of logging residues, stumps and small trees (i.e., forest chips) vary from 17.2 Mm^3 to 18.4 Mm^3 in 2030 (7.1 Mm^3 in 2010) across the scenarios. While this means a rather high increase in the relative sense, prices of forest chips are affected relatively little. Yet, the margin between the pulpwood price and forest chips prices is rather narrow: 8-10% increase in the prices of forest chips would make the use of pulpwood for energy economically feasible in 2030 in the scenarios Bio-Inno and Bio-Stor. In the scenario Crunch, softwood pulpwood and forest chips cost roughly the same in 2030. Figure 49 shows the relative price development with respect to the base year 2010.

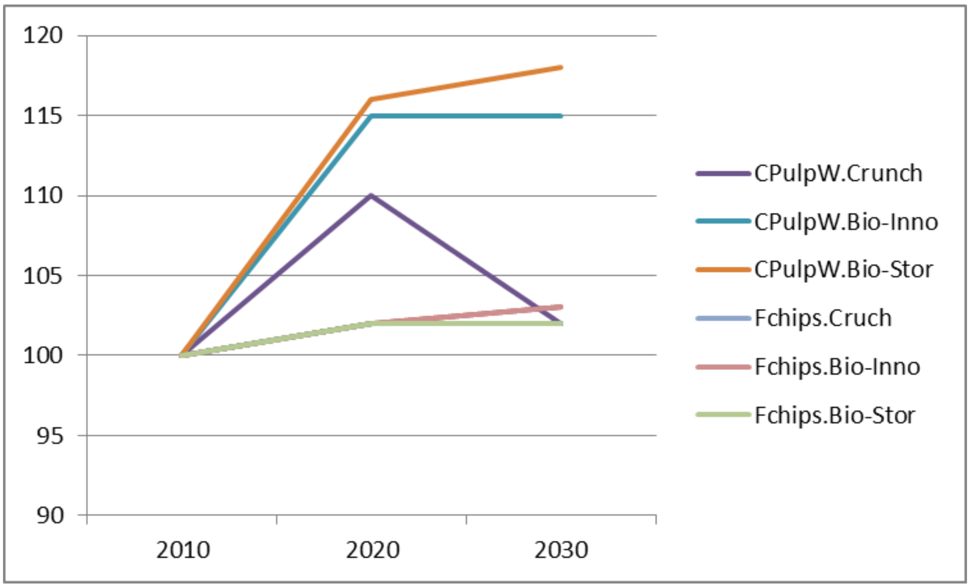

Figure 49. Development of the mill prices of coniferous pulpwood (CPulpW) and forest chips (Fchips) in Finland (2010=100).

Table 6. Roundwood and forest chips production in Finland and in the EU + 2 (the EU,Norway and Switzerland), Mm^3 (over bark). For 2010, the round wood harvests are from the statistics, but the amount of forest chips is estimate in the model.

	Finland 2010	Finland 2020	Finland 2030	Finland 2050	EU +2 2010	EU +2 2020	EU +2 2030	EU +2 2050
Crunch								
Softwood sawlogs	22	22	24	27	199	182	186	181
Hardwood Sawlogs	1	1	1	1	33	38	40	40
Softwood pulpwood	22	25	26	31	116	123	125	132
Hardwood pulpwood	7	9	9	10	50	50	49	55
Roundwood	**52**	**57**	**61**	**69**	**398**	**393**	**399**	**408**
Forest chips	**7**	**15**	**17**	**19**	**54**	**68**	**91**	**122**
Bio-Inno								
Softwood sawlogs	22	23	27	33	199	191	209	229
Hardwood Sawlogs	1	1	1	1	33	39	45	52
Softwood pulpwood	22	26	28	36	116	128	134	149
Hardwood pulpwood	7	9	10	11	50	51	53	65
Roundwood	**52**	**59**	**66**	**81**	**398**	**410**	**440**	**496**
Forest chips	**7**	**14**	**18**	**21**	**54**	**112**	**131**	**168**
Bio-Stor								
Softwood sawlogs	22	24	28	33	199	198	213	228
Hardwood Sawlogs	1	1	2	2	33	42	48	57
Softwood pulpwood	22	26	28	36	116	127	133	153
Hardwood pulpwood	7	9	10	10	50	51	52	68
Roundwood	**52**	**60**	**67**	**81**	**398**	**418**	**446**	**505**
Forest chips	**7**	**15**	**17**	**27**	**54**	**115**	**130**	**176**

8.2 Results for Europe and the whole world

8.2.1 Forest industry production

Tables 7 and 8 show the projected forest industry production in the pulp and paper industry in Europe and globally. Table 9 provides the respective data for the mechanical forest industry.

8.2.1.1 Printing and writing papers

The global consumption and production of printing and writing papers decline by about 27% from 2010 to 2030. The assumed differences in GDP growth rates between the scenarios do not spur important differences in the demand for printing and writing papers. The relative decline in production from 2010 to 2030 is slightly higher in the whole Europe (-45 – -52%)

than in Finland where the currently remaining machinery is rather efficient. In Latin America and in region “Rest of the world”, slight, yet unimportant, production increases take place.

Overall, the regional production quantities of printing and writing papers are more associated with the producers’ choice of maintaining or closing the existing production capacity than to their decisions upon new capacity investments. Any regional demand increases could be satisfied by machine rebuilds and relocations. These measures will continue to provide some business opportunities for machinery producers and consulting.

The fact that the outlook of the industry seems rather weak regarding to the consumed quantities may also provide some advantage for those incumbent producers which remain in the market in the longer run. Given the meager interest in investments in the new production capacity, the market prices could actually rebound to a higher level after the overcapacity has been removed.

8.2.1.2 Paperboard for packaging

The development of production of paperboard for different packaging purposes is varied across the continents. Globally, their consumption and production increase by 36–48% between 2010 and 2030. This 70–90 Mt increase in supply in the next couple of decades provides tremendous business opportunities also for the metal industries and services sector planning for these new production sites. The important capacity increases take mainly place outside Europe. In relative terms, the growth is projected to be highest in Latin America.

8.2.1.3 Household and sanitary papers

Production of household and sanitary papers grows in the same pace than that of paperboard. From 2010 to 2030, the global growth is 44–46%. There is relatively little variance across the scenarios, due to the low variance across assumptions on the growth of the GDP per capita in the emerging economies where more and more people are getting to use these products. The other markets are more mature. In every decade, some 6–7 Mt of new supply is projected to enter the market globally.

8.2.1.4 Chemical pulp

Sulfate pulp production increases globally by 8–9% from 2010 to 2030, with relatively narrow differences across the scenarios. Due to the decline in the production of printing and writing papers, about 14 Mt less bleached sulfate pulp is needed to these products globally in 2030 than in 2010, and this relieves the pressure for increased sulfate pulp production. Production of dissolving pulp and innovative pulp fibers is more varied in our scenarios, following directly from the assumptions made on their demand. In Bio-Inno, production of dissolving pulp, fluff pulp and new pulp fibers increases to 35 Mt in 2030, whereas the respective figure in Crunch is 10 Mt, yet considerably up from 2010. The increase is notable also in Europe, where more than 5 Mt of new advanced chemical fiber supply is projected to enter the markets by 2030 in the scenario Bio-Inno. In Europe, part of this development takes room from sulfate pulp production, which decreases in Bio-inno, but increases in other scenarios.

8.2.1.5 Sawn wood and plywood

The world's average increase in sawn wood and plywood production is highest in Bio-Stor, 36%, and lowest, 14%, in Crunch during 2010-2030. In Europe, the respective growth figures are meager, only 1% in Crunch and 9–10% in Bio-Stor and Bio-Inno. This is because the European markets for these products are somewhat mature and also slow-growing due to low population growth. The differences in the solid wood product output between the scenarios Bio-Inno and Bio-Stor in 2030 are more important in developing world and even in Eastern Europe than in the whole Europe.

Table 7. Production of pulp and paper products in the EU, Norway and Switzerland, millions tonnes

		Crunch			Bio-Inno			Bio-Stor		
	2010	2020	2030	2050	2020	2030	2050	2020	2030	2050
Printing and writing papers	44	29	24	22	26	21	20	27	23	20
Cartonboard and case materials	38	37	36	34	38	35	35	38	35	34
Household and sanitary papers	7	7	7	8	6	8	8	6	7	7
Other paper and paperboard	8	10	9	9	10	9	9	9	9	9
Paper and paperboard, Total	97	83	77	73	80	73	71	80	74	71
Sulfate & sulfite pulp	26	27	27	30	28	27	25	28	28	30
Dissolving pulp and new fibers	1	1	2	4	1	6	15	2	3	6
Sulfate pulp, dissolving and other fiber total	26	28	28	33	29	33	40	29	31	36

Table 8. Production of pulp and paper products in the world, millions tonnes

		Crunch			Bio-Inno			Bio-Stor		
	2010	2020	2030	2050	2020	2030	2050	2020	2030	2050
Printing and writing papers	143	113	105	104	112	104	101	112	104	100
Cartonboard and case materials	190	235	260	299	242	282	337	234	262	293
Household and sanitary papers	30	37	43	57	37	43	57	36	43	57
Other paper and paperboard	32	31	31	30	31	31	30	31	31	30
Paper and paperboard, Total	395	415	438	491	422	459	526	414	439	480
Sulfate & sulfite pulp	125	137	135	126	137	135	130	136	134	116
Dissolving pulp and new fibers	4	7	10	18	9	35	73	9	15	36
Sulfate pulp, dissolving and other fiber total	129	145	145	144		170	203	145	149	152

In absolute quantities, the projected increase in the world consumption and production of sawn wood and plywood is considerable, ranging from 64 Mm^3 in Crunch to 166 Mm^3 in Bio-Inno from 2010 to 2030. High production growth takes place in e.g. Eastern Europe and Latin America. The reasons for this growth derive both from the supply side (lower production costs) and demand side (higher demand growth rates). This provides a remarkable market opportunity to the machinery suppliers and for the companies supplying techniques for processing sawmilling residuals like bark and sawdust to energy (for instance CHP, ethanol and pellets).

8.2.1.6 Particle board and other panels products

In Western Europe excluding Nordic countries, the panel industry is shrinking in all three scenarios due to increasing production costs including those of wood input and due to competition coming from Eastern European producers that increase their production and market share. In Eastern Europe, production increase in this product group varies from about 2 Mm^3 in Crunch to over 19 Mm^3 in Bio-Stor (+15%–75%) during 2010–2030.

The global production of particle board, hardboard and MDF almost doubles in the scenario Bio-Stor, with an increase of 150 Mm^3 (89%) during 2010–2030. In the scenario Bio-Inno, the global growth is more moderate, 39%, and in Crunch it is 21%.

Table 9. Production of mechanical forest products in Europe (The EU, Norway & Switzerland) and globally, millions cubic meters

		Crunch			**Bio-Inno**			**Bio-Stor**		
	2010	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Europe										
Sawnwood	105	103	102	98	108	111	127	109	102	113
Other solidwood products	5	8	9	10	8	9	12	10	17	26
Particle board and other panels	54	43	37	28	48	47	43	53	57	54
Europe total	164	154	147	137	164	168	181	172	177	192
World										
Sawnwood	369	402	420	449	419	477	612	425	462	539
Other solidwood products	95	106	108	113	110	123	157	129	168	251
Particle board and other panels	175	207	211	209	216	243	293	246	330	468
World total	638	715	739	772	745	843	1061	800	960	790

8.2.2 Roundwood harvests

In the region formed by the EU countries, Norway and Switzerland, round wood harvests over bark in 2030 remain roughly at their 2010 level in the scenario Crunch, but increase to 440–446 Mm^3 in the other two scenarios (Table 6 above). Stagnated development of the total round wood harvests in the scenario Crunch is owing to the decreased demand for coniferous saw logs (-14 Mm^3 from 2010 to 2030). Pulpwood harvests increase by 5 – 9 % from 2010 to 2030 depending on the scenario. Harvests of forest chips for energy in the scenarios vary between 91 Mm^3 and 131 Mm^3 in 2030.

Globally, harvests of industrial round wood are at 23 – 38% higher level in 2030 than in 2010 in the scenarios. They range from 2036 Mm^3 to 2400 Mm^3 in 2030, being lowest in the scenario Crunch and highest in the scenario Bio-Stor.

8.3 Use of forest chips and round wood for energy

The demand for energy wood in the production of heat, power and liquid biofuels in industrial scale (Table 10) was projected by TIMES-VTT model and given as input to the EFI-GTM. With the concept "energy wood" we mean here
- forest chips
- industrial wood, which may also come from plantations and
- fuelwood directed from the household use to industrial use.

"Forest chips" include logging residues (branches and tops), stumps and small wood. "Industrial wood" mainly includes pulpwood chips made of pulpwood size wood harvested from forests or coming from sawmills as residual. It can also include saw logs, given that their price is low enough to be competitive. With "fuelwood" we refer to the traditional household fuelwood, which can be partly redirected in the scenarios for the use in modern heat and power production or in biorefineries making more advanced fuels.

8.3.1 Use of energy wood in Finland

Use of wood for bioenergy in Finland is increasing in all three scenarios in the projections made by TIMES-VTT energy system model. There is not much variation in the energy wood use across the scenarios by 2030. This is largely due to the fact that the EU 2030 climate and energy policy framework, including also national burden sharing of GHG emission reduction, was assumed in all the scenarios. In Finland, wood based energy is among the most economically and technically feasible options for achieving the reduction in the greenhouse gas emissions, including also the assumed 2030 targets for the non-ETS sector for Finland.

In Bio-Stor and Crunch, about 17.3 Mm^3 of energy wood is used in Finland and 19.3 Mm^3 in Bio-Inno in 2030. These quantities can be satisfied by harvesting more forest chips. In Bio-Inno, minor conversion of household fuelwood to modern fuelwood also took place. The share of wood going to biorefineries producing liquid biofuels, i.e. mainly for transport, from the total energy wood demand ranges from 20-28% in 2030.

8.3.2 Use of energy wood in Europe and globally

In Europe (the EU + Norway + Swizerland), the use of energy wood in 2030 varies from 114 Mm^3 in Crunch to 150 Mm^3 in Bio-Stor. Yet, more pulpwood is used for energy in Crunch (22 Mm^3) than in Bio-Stor (10 Mm^3). This is because of the lower pulpwood prices in Crunch. About 7-8% of energy wood in the scenarios Bio-Stor and Bio-Inno (13-14 Mm^3) are coming from traditional fuelwood assumed to be shifted to industrial uses. The share of wood going to biorefineries producing liquid biofuels from the total energy wood demand ranges from 10-15% in 2030.

Globally, the use of energy wood triples (Crunch) or even quadruples by 2030, varying from 680 Mm^3 in Crunch to 960 Mm^3 in Bio-Stor. Still, only 1-10 % of the energy wood demand in 2030 needs to be satisfied by using industrial wood. Intensified harvests of logging residues is projected to play the most important role in meeting the increased demand. Also, increased use of plantation wood and redirecting fuel wood from cooking and heating needs of households to industrial use are important factors in responding to the growing demand for woody biomass energy. Together the latter two sources satisfy about one third of the increased energy wood use from 2010 to 2030.

Table 10. Assumed demand for energy wood for heat and power (h&p) and liquid fuels in the scenarios (TWh) as obtained for input to EFI-GTM from TIMES-VTT. 1 TWh is roughly 0.5 Mm^3 of wood. Following the TIMES-VTT regional borders, Europe includes the EU28, Norway, Switzerland, Bosnia-Herzegovina, and Serbia.

			2010	2020	2030	2040	2050
Finland	Crunch	h&p	15	26	26	28	31
		liq. fuels	0	4	9	19	16
		total	15	30	35	47	47
	Bio-Inno	h&p	15	26	28	32	27
		liq. fuels	0	3	11	13	9
		total	15	29	39	45	36
	Bio-Stor	h&p	15	27	27	27	24
		liq. fuels	0	3	7	13	18
		total	15	30	34	40	42
Europe	Crunch	h&p	152	172	203	243	250
		liq. fuels	0	14	35	63	74
		total	152	186	238	306	324
	Bio-Inno	h&p	152	238	261	258	242
		liq. fuels	0	13	30	176	230
		total	152	251	291	434	472
	Bio-Stor	h&p	152	238	265	255	225
		liq. fuels	0	14	38	177	287
		total	152	252	303	432	512
World	Crunch	h&p	458	975	1153	1219	1793
		liq. fuels	2	185	265	884	828
		total	460	1160	1418	2103	2621
	Bio-Inno	h&p	458	1283	1300	1250	1837
		liq. fuels	2	196	570	2130	2754
		total	460	1479	1870	3380	4591
	Bio-Stor	h&p	458	1244	1313	1498	1964
		liq. fuels	2	206	685	2250	3422
		total	460	1450	1998	3748	5386

Globally, the share of wood going to biorefineries producing liquid biofuels from the total energy wood demand is higher than in the EU. It ranges from 19-34% in 2030. Well over 50% of the wood based biofuel production (measured from quantity of wood biomass going to that industry) will take place in China according to the projections of VTT-TIMES model. By 2050, production in China is diminishes and Latin America is projected to take a leading role in biofuels production. In the scenario Bio-Inno, almost 40% of the total consumption of energy wood is used in biofuels production.

8.4 Sensitivity analyses

8.4.1 Constant forest area and constant use of traditional fuel wood

The assumptions presented in section 6.2 on increasing forest plantation area and release of traditional fuel wood to modern uses are crucial in meeting the demand for energy wood projected by the energy system analysis (Section 7) and preventing the prices of wood biomass to sky-rocket. This is particularly the case in the scenarios Bio-Inno and Bio-Stor with tight climate policies. In these scenarios, the lack of these additional wood supply sources would cause very high wood prices even in Finland and Europe where the demand-supply balance would not be expected to be that tight. This is due to international trade. Relying solely on the current wood supply sources would make the projected softwood pulpwood prices to be 31% higher in Finland and 26% higher in Europe in the scenario Bio-Inno in 2030. By 2050, when the bioenergy demand has grown markedly higher, the markup in the pulpwood price without these additional wood supply sources is 130-150% compared to the case with them. In 2050, costs of logging residues would more than triple to 140 €/m^3 in Bio-Inno and 170 €/m3 in Bio-Stor even in Finland. By 2050, about 1000 Mm^3 of wood suitable also for forest industry production would be used in energy production globally in Bio-inno and 1400 Mm^3 in Bio-Stor. Naturally, under such prices, modern energy wood demand would probably not reach such high levels in the first place. Nevertheless, the results suggest that with the current forest area and current traditional fuel wood demand, the projections presented would be highly ambitious and hard to achieve, particularly after 2030.

In scenario Crunch where wood demand is lower both in the forest industry and in the energy sector, the prices of round wood and forest chips would remain in more “affordable” levels even with wood supply sources unchanged from 2010. Forest chips prices are up by 2% in Finland and 18% in Europe in 2050 when we compare the projected prices without and with additional supply sources. Pulpwood prices would be about 27% higher both in Finland and in Europe in 2050. Globally 370 Mm^3 of wood suitable for the industrial processing would be used to produce heat, power or liquid biofuels. Even that amount is remarkable: more than 60 Mt of chemical pulp for instance for the production of textiles could be produced from such wood quantity.

8.4.2 Energy wood demand staying at 2010 level

Running the forest sector model with bioenergy demand fixed to 2010 level gives some indication what is the magnitude of impact of increased demand for energy wood on the round wood market.

Assuming that the forest industry product demand develops as in scenario Crunch with energy wood demand remaining in its 2010 level, wood prices would decline in all wood categories other than hardwood saw logs in Europe from 2010 up to 2030. By 2050, also hardwood saw logs would cost less in 2050 than in 2010. Use of wood in the forest industry develops weaker than the increasing wood supply in Europe. Compared to the actual Crunch case with increased energy wood demand, pulp wood prices would be 6% lower in 2030. So, this is the magnitude of cost push caused by the energy sector’s increased participation in the wood market in the scenario Crunch. In Europe, this would hinder pulpwood prices from declining after 2010.

In scenario Bio-Stor, the impact of the increased energy wood demand on the pulpwood market prices in Europe is of the similar magnitude than in Crunch. Mill prices for pulpwood in scenario Bio-Stor are 3-4% higher in 2030 with increased use of wood for energy. Yet, as the increase in the energy wood demand and increasing wood prices due to it are global phenomena, the forest industry is exposed to it everywhere. Consequently, the production is not much affected as the cost increases can be transferred to relatively inelastic end product prices. If energy wood demand would increase in Europe only, like it has been considered in some other studies, situation would be different. Then the producers in affected countries would more easily lose market share to the other regions.

8.5 Discussion

In the BEST scenarios, demand for energy wood (forests chips and round wood used in producing modern bioenergy and liquid fuels) increases considerably already by 2030, and even more so during 2030–2050 totaling about 2600–5400 TWh (9.4–19.4 EJ) in 2050. The increase in the demand for this “modern energy wood” is considerably higher than the total increase in the use of woody biomass for primary energy discussed in Section 7. In 2010, more than half of the round wood harvested, almost 1900 Mm^3 or circa 14 EJ, was consumed by households as fuel wood (FAO, 2014). In the BEST scenarios, the direct fuel wood use of this type was projected to decrease considerably.

The high increases in biomass consumption for energy is projected to take place all over the world, and not only in the EU, which has already set ambitious goals for cutting greenhouse gas emissions. Some earlier analyses on the EU energy wood market (e.g. Moiseyev et al. 2014) set out from the assumption that the EU could satisfy its growing biomass demand with increased imports. Obviously this option is not that feasible with the globally increasing biomass demand. Instead, it is even possible that there will be pressure to start exporting woody biomass out of Europe, if its global demand develops like assessed in the scenarios.

Despite the fact that the use of modern energy wood seems to be increasing drastically in the scenarios, it is notable that in the bigger picture wood biomass has less important role as a source of primary energy. According to the results presented in section 7, the vast majority of the energy biomass continues to come from agricultural sector. A vital question is how this may influence food production.

In scenario Crunch, the demand for wood in the forest industry and the energy sector increases moderately in relation to the wood supply potential. The market for wood biomass is not very tight in that scenario by 2030 or even later on. In the other two scenarios, Bio-Inno and Bio-Stor, the wood market becomes tighter. Still, before 2030, the use of material wood (pulpwood and sawmill chips) in the energy production and thereby the question of competition between the forest industry and the energy sector over wood will not necessarily become an important issue. Energy wood demand can to a large extend be satisfied by intensifying the production of forest chips. According to the model projections, the increase in pulpwood prices that can be attributable to the increased demand for energy wood is well below 10% in all scenarios for Europe by 2030. After 2030, it becomes crucial that additional sources for wood biomass will become available in a form of fast-growing wood from plantations and household fuel wood released to modern energy production. The latter development is important also in order to diminish local air pollution. Yet, considering the importance of the fuel wood as energy source of the poorest households in the developing countries and often, relatively sparse population densities, this development has to take place rather soon and requires a relatively large rise of the living standards in these countries.

In the pulp and paper industry, novel pulp fibers, paperboard for packaging, and household and sanitary papers belong to the products with highest demand growth prospects. Although the growth in these products is strongest outside the EU, it provides business opportunities for international forest industry companies, metal industries and services branch in Europe too. Similarly, business opportunities are offered in the mechanical forest industry that is projected to grow in the solid pace with increasing population and purchasing power.

9 Conclusions

In this report, we assessed the future demand for biomass and use of bioenergy in three alternative operational environments shaped by different assumptions on the economic, technological and regulatory aspects. The emphasis of the model-aided scenario work was set on the time period up to 2030, but developments up to 2050 were sketched as well. Two large scale techno-economic models soft-linked to each other were used to quantify the impacts of the scenario assumptions: the TIMES-VTT model of global energy systems and the EFI-GTM model of global forest sector.

At present, most of the global bioenergy is consumed in traditional small scale uses. In the future, this picture is expected to change radically. According to the energy systems analysis documented in this report, the total bioenergy use could double to over 100 EJ during 2010–2030. About one third of that amount could be utilized for power and heat production in the energy sector and industry. The largest utilization level is reached in the Bio-Inno scenario, where Europe is in the forefront of bioenergy technology development. Yet, the Bio-Stor scenario is not left much behind in bioenergy utilization despite having a higher penetration of other renewables.

When going beyond 2030, the analysis indicates that global bioenergy demand could again nearly double between 2030 and 2050, reaching up to 180 EJ in the scenarios where the warming of climate is limited to 2 °C through global efforts. Then about 90% of the estimated sustainable global biomass potential would be taken into use. More than half of the total increase would be used for producing liquid biofuels, mainly for the transport sector. The largest contribution to the increase in bioenergy use would come from energy crops, most clearly when moving beyond 2030. Even though modern energy wood does not play a major role in the total energy biomass palette, its use increases so much that it is essential to have additional supply sources for wood. The development calls for increases in the forest plantation area and large scale shift from traditional fuel wood use to modern bioenergy.

The high degree of utilization of the global biomass potential suggests that close to all economically and technically feasible biomass sources will be taken into use in the long run. However, it should be kept in mind that there are large uncertainties related to future potentials and price levels of bioenergy feed stocks due to competition of land for food and feed, increased use of biomass on materials and chemicals, and, on the other hand, tightening sustainability criteria of biomass feed stocks for energy and liquid biofuel production. This makes the availability of sustainably produced biomass to be of a critical concern in the long run. Sustainable biomass production should avoid any adverse side effects on food and feed production and greenhouse gas balances due to land-use change. That calls for international agreements on the criteria for sustainable biomass as well as monitoring mechanism to ensure consistency and transparency.

In Europe, total primary energy consumption is decreasing. Yet, growth is expected in electricity demand. In particular, tight climate policies would boost electrification in all sectors. The potential for increasing bioenergy use in Europe is strongly focused on agro-biomass, i.e. energy crops and agricultural residues. Although the prospects for increasing the use of wood biomass for energy are also notable, over 1 EJ, it is largely associated to enhancing the recovery of forest residues. For decarbonising the transport sector in Europe, utilization of the agro-biomass potential will thus be crucial, which may raise issues of sustainability. The results show quite high increases in energy crop production, but the overall bioenergy results appear to be in a good agreement with the trends in the national renewable energy projections.

Finland is at an exceptionally high level in modern use of biomass for energy compared to other OECD countries. Most of the bioenergy in Finland is produced from forest biomass, both today and in the foreseeable future. By 2030, about 75% of the increase in bioenergy use is projected to come from forest residues.

The demand for bioenergy in Finland concentrates on power and heat production in the industry and energy sector, which covers about 80% of bioenergy consumption. While Finland is already one of the forerunners of employing combined heat and power (CHP) for efficient power and heat production, bioenergy would become an increasingly important energy source in community power plants. Under tightening climate policies, the future of wide-scale district CHP generation in Finland appears to be largely dependent on bioenergy supply. On the technology front, the model results indicate that gasification combined-cycle technologies may be expected to be among the key bioenergy technologies for CHP, while in the short term FBC technologies and biomass co-firing options still have a major role. In addition, in the Bio-Stor scenario, synthetic natural gas (SNG) production becomes a competitive option of producing biogas into the gas network for use in power and heat production and industry. By 2050, new technologies that offer higher power-to-heat ratios and flexible operation to support the wide integration of variable renewable generation may become competitive. As an example, solid oxide integrated gasification fuel cells entered into the market by 2050 with optimistic assumptions on costs and technology development.

Bioenergy thrives almost equally well in Finland in all of the three scenarios. In the Crunch scenario, the high fossil fuel prices make bioenergy an attractive option. In the Bio-Inno scenario, rapid development of bioenergy technologies and carbon capture and storage integrated to biomass fired plants (i.e. BECCS) offer new business opportunities both in power and heat production and biorefineries in the long run. However, there are still large uncertainties related to commercialisation of CCS and currently there is no policy framework for BECSS either.

In the Bio-Stor scenario with less new nuclear power in Europe, the emission allowance prices rise to the highest levels and improve the competitive position of all renewables. Bioenergy based thermal power is needed for counterbalancing the large amounts of variable generation from wind and solar.

If the world countries are able to commit themselves to limit the climatic warming to 2 C decrees, producing biofuels from sustainably produced biomass in biorefineries equipped with CCS can become an attractive option (i.e. BECCS). It would not only reduce emissions by replacing fossil fuels in transport sector, but it would also create a stream of negative net emissions by storing a major part of the organic carbon in a carefully selected geological formations. These negative emissions can offset greenhouse gas emissions in other sectors, where GHG mitigation is very expensive or even impossible with the current knowledge. The emission reduction would perhaps be the highest in BECCS power plants, as there almost all of the carbon content of biomass could be captured. However, the overall economics of

BECCS appears to be best in biorefineries, which produce practically pure CO_2 and therefore there is no need for energy intensive capture of CO_2.

Sustainable bioenergy can be one of the cornerstones of renewable energy supply when moving to a low carbon society. Nonetheless, due to the limits on sustainable bioenergy production, a wider portfolio of renewable energy sources and technologies will be necessary for reaching the policy targets to tackle the climate change. Furthermore, considering the high demand for energy biomass projected in the scenarios, it is essential that technical improvements and innovations take place in all areas to relieve the pressure on the resources, let it be energy production and storage, use of energy, or use and reuse of biomass, materials and land.

Numerous uncertainties prevail behind the scenario projections. As mentioned above, the sustainability criteria of biomass will need to be developed further, and once that happened, the new criteria may affect the question, to which extent different biomass grades will be considered to be carbon neutral and thus applicable to reduce greenhouse gas emissions in the future. If the palette of biomass sources usable for achieving emission reduction targets is narrowed, the use of other, more costly, carbon neutral energy forms would need to be increased. Future LULUCF (i.e. land use, land use change and forestry) policies are partly tied to that issue. For instance, if changes in carbon stored in forest land would be fully accounted as a part of the annual CO_2 emissions of the countries that might bring in changes to forest policies and decrease both the round wood supply and wood use in the countries affected.

Regarding agro-biomass, the question of the population development, development of the dietary habits and technological change in agriculture are decisive in determining the availability of land for energy biomass supply. Another important and uncertain issue is the impact of climate change on the future harvest levels.

Political choices both in individual countries and in international level are of great importance in shaping the future global use of energy. In the scenarios Bio-Inno and Bio-Stor, it was assumed that the climatic warming is limited to 2 C degrees. This calls for strong commitment of the countries toward achieving this goal to be taken soon. If this will not happen, like it was assumed in scenario Crunch, less biomass will be used for energy globally. Still, the decisions already made in the EU create raising markets for bioenergy technology.

In the forest sector, demand for wood pulps is increasing particularly in the production of traditional and new packaging materials, household and sanitary papers, textiles, fluff pulp and novel fibre uses. This development more than offsets the declined demand for wood in production of printing and writing papers, the demand for which is projected to decline globally. The same kind of wood raw material is also used in the production of boards, like OSB or particle board. While there is some competition over wood fibre between the forest industries and energy sector, the production of the former is not much affected. Yet, the pulpwood prices increase in some degree due to competition. The production and consumption of solid wood products, sawn wood and plywood increase considerably as well. This eases the supply of sawmill chips and logging residues. Overall, the most important increases in the forest industry production take place outside the EU, because the markets are already relatively mature in Europe. Nevertheless, the global growth in many product areas provides abundant business opportunities for international forest industry companies and suppliers of machinery and services also in the EU.

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