European Union Wood Biomass Demand for Energy Purposes and its Influence on U.S. Southeastern Forest Market and Carbon Storage

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Master Thesis no. 184

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BIOGRAPHY

Rafal Chudy is a forestry student from Poland. He received his Bachelor degree in multifunctional forestry at Warsaw University of Life Sciences. He was taking part in EUROFORESTER Master Program at Swedish University of Agricultural Sciences (SLU). Next, he continued his studies in the EU-US Transatlantic Masters Degree Program in Forest Resources, spending one semester at University of Helsinki and one year at North Carolina State University. During his studies in the United States of America, he did an internship at United States Department of Agriculture (USDA), doing research about economic comparison of alternative water supply sources across eastern Africa.

ABSTRACT

Energy supply combined with reduction of greenhouse gas emissions is a global concern. The European Union (EU) has set an ambitious target to achieve 20% of energy sourced from renewables by 2020. Biomass imports are likely to make an important contribution in the EU's renewable energy consumption. The Southeastern U.S. is considered as one of the potential biomass import regions to the EU. The SubRegional Timber Supply Model (SRTS) was used to observe market reaction on changes in woody biomass consumption. The research area included Southeastern U.S and its coastal plain. The results from sensitivity analyses demonstrate that neither percentage of biomass delivery to EU nor moisture content of pellets significantly influence the wood market in the Southeastern United States.

Next, the results from modeled scenarios show that for both regions and under all projected scenarios, price increases range from 25% up to 125%. Furthermore, the costs of EU imports are very sensitive to U.S. domestic renewable energy policy which is uncertain. Under all scenarios and for both the Southeast and coastal plain, carbon storage increased due to positive market planting response among private forest owners compare to baseline scenario. While low and medium scenarios were very similar in terms of impact on market behavior, high scenarios for both SE U.S. and coastal States' cause the biggest impact on wood markets and natural resources in these regions.

Keywords: Pellets, International wood trade, Southeastern U.S., EU, forest market, carbon storage

DEDICATION

To my parents, Jacek and Anna Chudy, for their unconditional love and support.

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Foremost, I would like to express my sincere gratitude to my advisor Robert Abt for continuous support of my Master thesis study and research. Besides, I would like to thank the rest of thesis committee: Frederick Cubbage, Jeffrey Prestemon and Ragnar Jonsson for cooperation and valuable comments that helped me to develop my research skills and accomplish Master degree. Last but not least, I want to say big thanks to my family and my girlfriend Evgenia who supported me from distance all the time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION AND OBJECTIVES

Energy supply and the reduction of greenhouse gas emissions is a global concern. The European Commission, has set an ambitious target to achieve twenty percent of energy sourced from renewable sources by 2020. Meeting national targets for renewable energy will require intense mobilization of domestic sources as well as increased imports (see e.g., Mantau et al. 2010a). Hence, biomass imports are likely to make an important contribution in the EU's renewable energy consumption. The European Union (henceforth EU) has declared it will use wood from sustainable sources only.

The federal government of the United States (henceforth U.S.) also has a number of policies in place to promote the use of bioenergy. Currently, the merits of these policies and the impacts on biodiversity, climate change, and land use are under discussion. This discussion is of interest for the EU, in the light of bioenergy trade.

Because of fast growing conditions, huge forest resources and relatively cheap transatlantic freight, the EU considers Southeastern United States (U.S.) a very attractive region for sourcing woody biomass imports. At present, there is lack of knowledge as to how forest inventories, forest-product markets and forest carbon in the Southeastern United States could be affected by the European energy sector. Hence, sustainable forest management and wood market in the Southeastern U.S. will face many obstacles and problems in terms of satisfying domestic and EU bioenergy demand.

The objectives of this thesis are to:

i. assess the impact of EU energy consumption on wood pellet imports between 2008 and 2038
ii. determine the influence of U.S. and EU wood fuel feedstock consumption on the Southeastern forest market and carbon storage

The first question is addressed by means of a literature review. For the second objective, the Sub-regional Timber Supply Model (SRTS) is used to observe market reactions from changes in woody biomass consumption (Abt et al., 2009). Due to uncertainty about future markets and policy, a key aspect of this research is to conduct sensitivity analysis to identify key variables that will influence future market and resource characteristics.

LITERATURE REVIEW

The objectives of this literature review are to review bioenergy policy in the U.S.A. and EU, present trends and motives for ‘green energy’ development in modern world, and finally discuss the importance of international woody biomass trade with special attention on the pellet market. Finally, the literature review includes presentation of available models with potential to characterize and project biomass demand, and supply.

Drivers of wood-based energy demand and trade

Around the world, there is a growing interest in finding ways to use woody biomass to meet needs for energy and raw materials. There are many benefits associated with the utilization of woody biomass for bioenergy and bio-products, environmental, economic, and energy security related. Moreover, the utilization of woody biomass may benefit the forest ecosystem, the global environment, forest landowners, and society (Abt et al., 2010). What is the ability to supply wood over the next decades? How much should national energy policy rely on woody biomass? To answer these questions proper market analysis has to be done.

International Energy Agency (IEA) Bioenergy Task 40 predicts that global bioenergy trade will develop into a ‘global commodity market’, which will secure supply and demand in a sustainable way. Imports of biomass are predicted to increase in the coming years for most of the European Task 40 member countries (such as Belgium, Brazil, Canada, Finland, Norway, Netherlands, Sweden, and United Kingdom). The IEA claims that the main driving force behind bioenergy expansion is the potential to provide an affordable and practical renewable source of energy for climate change mitigation, energy security, and rural development (Junginger et al., 2008).

Magar et al. (2010) maintain that bioenergy production and trade driven by climate change concerns, emissions reduction targets, increasing concerns about domestic energy security and favorable policies - will likely continue to increase in the future. According to

Berndes (2010), practically all bioenergy systems deliver large greenhouse gas (GHG) savings if they replace fossil-based energy causing high GHG emissions and if the bioenergy production emissions- including those arising due to land use change- are kept low. According to Faaij (2006), one of the key options on shorter and medium term to mitigate greenhouse gas (GHG) emissions and substitute fossil fuels can be use of bioenergy. Similar causes of increasing biomass use were described in: AC/UNU (2007); Broadmeadow, (2004); Collins (2006); FAO (2007); Hansson and Berndes (2006); Berndes and Hansson (2007).

In Europe, programs are executed for developing and stimulating bio-energy, both on EU and national level. Hence, every country in Europe has included bioenergy in its energy and climate policies (Faaij, 2006). Currently, increased prices for fossil fuels stimulate the use of alternatives (among them wood for energy).

Development in trade of emissions and systems with green certificates for electricity increase the demand for all renewable energy including wood fuel (Hillring, 2006). Junginger et al. (2008), agrees that favorable policies for renewable electricity energy production and use (e.g. electricity, heat and transportation fuels) are a main driver for the import of biomass and may drive up prices of biomass as well. Prices in favor of biofuels for transport play an important role as a driver for import of biofuels. Major drivers for international bioenergy trade, also comprise large resource potentials and relatively low production costs in producing countries such as Canada and Brazil, high fossil fuel prices, and various policy incentives which stimulate biomass use in importing countries (Junginger et al., 2008). Abt et al. (2010) asserts that state and federal policies are key factors which drive production of renewable energy (renewable portfolio standards) and liquid fuels (renewable fuel standards). There are predictions that over the next decade the infrastructure for renewable energy supplies is unlikely to develop as fast as policy and market motivated renewable energy demands (Abt et al, 2010).

For many people all over the world bioenergy seems to be more environmentally friendly and safe than nuclear power that is arousing plenty of controversies today. In Germany, the phasing out of nuclear power and the circumstances that a large portion of the renewable energy is expected to come from woody biomass, could lead to a significant increase in the demand for woody biomass (see e.g. Ekstrom, 2011). Following the recent crisis at the Fukushima Dai-ichi nuclear plant in Japan in 2011, the nuclear power development is questioned in many countries. According to the Economist, in the European Union Austria, Denmark, Greece, Ireland and Portugal are strongly antinuclear. Moreover, in Germany in 2002 the centre-left government said it would phase out nuclear power by 2022. (The Economist, March 26th-April 1st 2011). Countries such as Finland, Poland and Switzerland are also starting to question the viability of nuclear power as a future source of energy (Ekstrom, 2011).

Furthermore, environmental concern has become a strong driver behind the increased interest for wood energy in the past years (Hillring, 2006). At the same time it is advocated by, amongst others, the Manomet Center for Conservation Sciences (Manomet Center, 2010) that demand for forest biomass must not result in deforestation, soil degradation or loss of biodiversity. To solve the problem of environment degradation, controls to assert that bioenergy facilities source wood from forests with approved management plans, or allowing bio energy facilities to self-monitor for sustainable practices, are recommended.

European Union energy policy

Fossil fuels imports from third countries strongly affect European Union energy supply, economic stability and independence. To reduce greenhouse gas emissions and comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and tackle the issues of energy supply, the EU's Renewable Energy Directive (2009/28) sets an overall binding target of twenty percent for the share of EU energy needs to be sourced from renewables such as biomass, hydroelectric, wind and solar power by 2020. Moreover, at least ten percent of each Member State's transport fuel use must come from renewable sources (including biofuels). For comparison, in 2008 renewable energy accounted for 10.3% of gross final energy consumption in the EU-27, the remaining 89.7% was covered through the use of conventional fuels such as natural gas or oil products.

The renewable energy share in gross final energy consumption was used for the production of heat (5.5%), electricity (4%) and for transport fuels (0.8%) (Roubanis et al., 2010).

The European Commission proposal is to maintain the EU's position as a world leader in renewable energy (Peksa-Blanchard et al., 2007). The shares of renewable energy in total energy consumption vary significantly among Member States, mainly due to differences in renewable energy potential and degree of exploitation of the available natural resources. Hence, the Community twenty percent target is translated into individual targets for each Member State. On the other hand, the ten percent target for transport fuel from renewable sources applies to all Member States, this is in order to ensure consistency in transport fuel specifications and availability. According to European Union policy, every Member State is obliged to adopt a national renewable energy action plan, which will include national targets for the share of energy from renewable sources consumed in transport, electricity and heating and cooling in 2020. Share of renewable energy in gross final energy production between 2006 and 2008 for European Union countries with planned targets can be found in the Appendix A. Countries that are characterized by high renewable potential already have reached planned targets or they are very close to success in coming future while some of the countries still struggle many problems to achieve projected objectives.

Figure 1 shows that the EU non-biomass renewable energy potentials lie in the wind energy onshore (mostly Northern Europe- Scandinavia, United Kingdom, partly coast of France, Germany, Netherlands, Belgium), solar energy (Southern Europe- for example Spain, Italy, the Balkans) and wave energy (mostly west coasts of Scandinavia, the United Kingdom (henceforth the UK), southern Island). Even though these sources of renewable energy provide alternatives to fossil fuels, the potential is not sufficient for fully satisfying energy demand, in particular for the countries in the Central and Eastern Europe (such as central France, Germany, Poland, Alpine countries, Benelux countries), Baltic countries and Finland, which are scarce in these kinds of renewable sources. Hence, biomass is expected to be one of the main (if not the main) solutions to achieve the renewable energy targets.

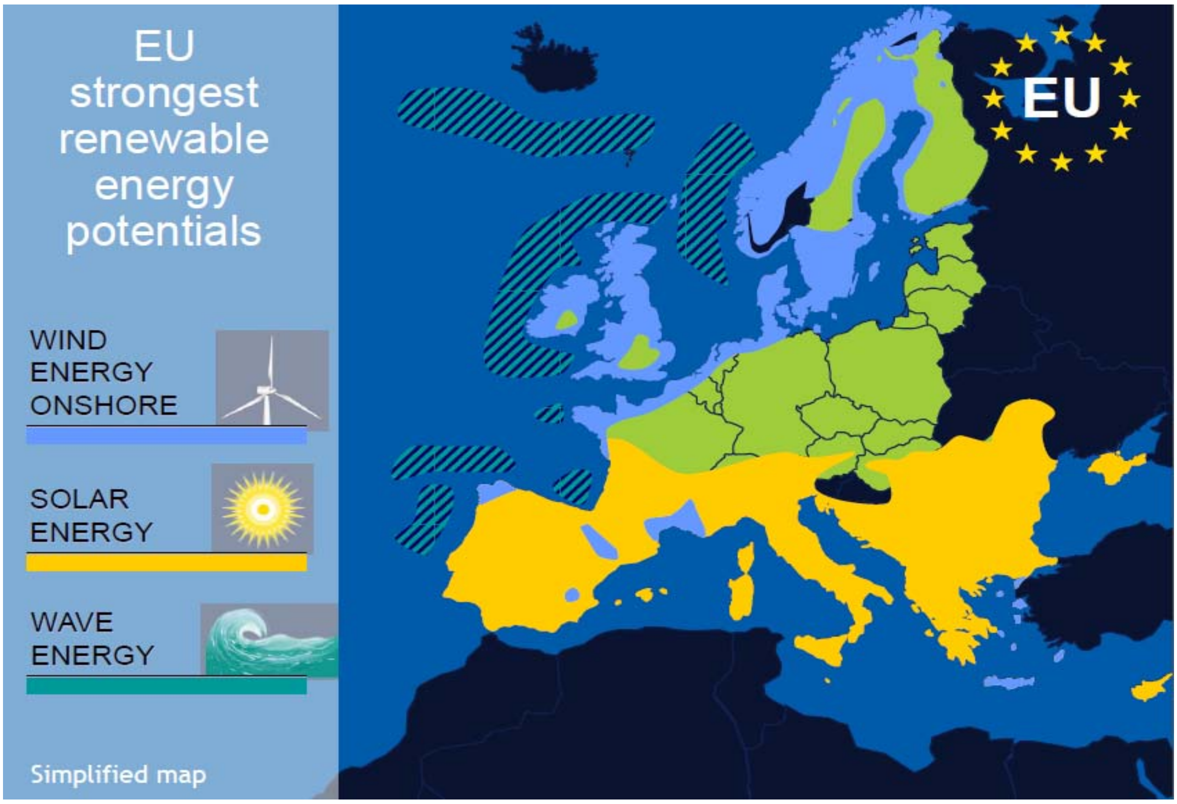


Figure 1. EU strongest non-biomass renewable energy potentials (Source: Energy for a Changing world: Europe's New Energy Policy)

According to Eurostat database, biomass and renewable wastes provide around 68% of renewable energy primary production within EU (Figure 2) and have the largest contribution potential for reaching EU's renewable targets in the future (Eurostat, 2011) as well in GHG emission reduction (biomass for energy production is considered CO_2 neutral). Hydroelectric power, wind power, geothermal and solar energy contribute: nineteen, eight, four and one percent respectively.

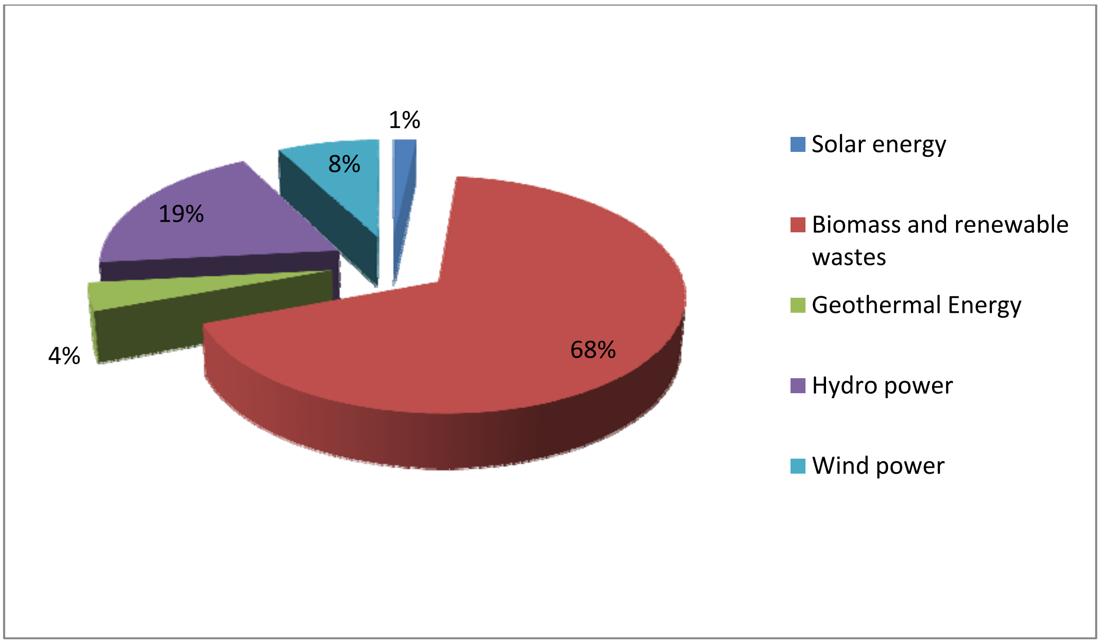


Figure 2. Renewable energy primary production: biomass, hydroelectrical, geothermal, wind and solar energy in 2009 (Source: Eurostat)

Countries (such as the Netherlands, Belgium, Denmark, and the UK) have low availability of biomass. They are expected to rely to a large extent on biomass imports to achieve the EU energy policy objectives. In general, the EU is not considered as a region with a high ratio of biomass production potential to expected energy demand, and thus biomass imports are likely to make an important contribution to EU renewable energy consumption (European Commission, 2007).

There are predictions that pellets and other types of woody biomass could significantly contribute to the target of twenty percent of energy from renewable sources by 2020 (Sikkema et al., 2011). According to Peksa-Blanchard et al. (2007), wood fuels (including wood pellets) are the most readily available biomass form in most of the European countries and they will play a crucial role in achieving the 2020 objective. Moreover, bioenergy trade (imports) represents a great opportunity to achieve even higher shares (Peksa-Blanchard et al., 2007).

In Europe, environmental criteria on GHG emission reductions, biodiversity conservation and good environmental management practices are included in the Renewable Energy Directive (DIRECTIVE, 2009). The control of European energy consumption and the increased use of energy from renewable sources, together with energy savings and increased energy efficiency will constitute important points to meet desirable targets by European Union energy policy. To meet required objectives, it is incumbent on Member States to make significant improvements in energy efficiency in all sectors in order more easily to achieve their targets for energy from renewable sources, which are expressed as a percentage of gross final consumption of energy.

The current objectives of EU renewable energy policy are stated in the first paragraph of Directive 2009/28/EC (the 'Renewable Energy Directive) as (i) reducing GHG emissions, (ii) enhancing security of energy supply, (iii) promotion of technological development and innovation, and (iv) provision of opportunities for employment and regional development, especially in rural and isolated areas. Generally, the EU Directive describes three options to reach the twenty of renewable energy in total energy consumption by 2020:

- The use of renewable electricity
- The use of renewable energy for heating and cooling
- The use of renewable transportation fuels (e.g. liquid biofuels).

According to Peksa-Blanchard et al. (2007), concerns about climate change and targets to realize renewable electricity targets are a predominant driver in Europe, especially for large-scale co-firing. Also the price advantage/competition with fuel oil plays an important role. The second driver is also the predominant one for North America, combined with a desire to diversify fuel supply (Peksa-Blanchard et al., 2007).

According to annual market review of forest products between 2009 and 2010, Europe continues to be the centre of the global wood energy market in that the EU “20:20:20” target lies at the heart of current and future growth in wood energy demand (Forest products annual market review 2009-2010, 2010). Target “20:20:20” means a reduction in EU greenhouse gas emissions should be at least 20% below 1990 levels, 20% of

EU energy consumption should come from renewable resources and 20% reduction in primary energy use compared with projected levels should be achieved by improving energy efficiency. The rapid growth in demand for wood energy has created concerns about how to ensure the sustainability of wood fuels. The European Union held debate about implementation of EU- wide sustainability criteria. Finally, in spring 2010 the EU decided that natural resources sustainability should be determined at the individual member state level (Forest products annual market review 2009-2010, 2010).

According to a study by Mantau et al. (2007) on EU and European Free Trade Association (EFTA) level, wood consumption (821 million m3) exceeded production (775 million m3) in 2005. This indicates that biomass imports can be significant in the near future for the EU.

Magar et al. (2010), maintain that there is still a lot to do in the development of the bioenergy sector within the EU. While survey results show that: bioenergy use is publicly accepted in Europe, a coherent trade framework is needed to boost and regulate bioenergy trade in the EU, and there is a lack of European standards for bioenergy production, trade and development. Moreover, a majority of the respondents to the survey agreed with the statement that the EU still does not have a competitive and well-functioning bioenergy market. Competition between market players seems to be very important for future development of technology and environmental sustainable industry. One of the key results in this article was the quite strong agreement among respondents that certification of bioenergy can be necessary to promote its sustainable use and the development of trade (Magar et al., 2010).

U.S. bioenergy policy and development

In the USA there are a number of instruments either at the federal level or state level influencing biomass energy production or use (Peksa-Blanchard et al., 2007). Two programs were introduced in the early 1990s as part of the Energy Policy Act of 1992, providing incentives for electrical generation from green energy sources at the federal level. First is the

Renewable Energy Production Incentive (REPI) that provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Facilities are eligible for annual incentive payments of 1.5 cents per kWh (1993 dollars and indexed for inflation) for the first ten year period of their operation, subject of the availability of annual appropriations in each Federal fiscal year of operations. The second newly introduced program, the Renewable Energy Production Tax Credit (REPTC) allowed the same 1.5 cents per kWh (real 1993 currency) incentive to private facilities in the form of tax credit available to facilities generating electricity from wind, closed-loop biomass, or poultry waste. The program was renewed in 2004 for another decade and the list of eligible energy sources has been expanded to include open-loop biomass, solar, municipal solid waste, geothermal, and small irrigation power (Peksa-Blanchard et al., 2007).

On August 8, 2005, the Energy Policy Act of 2005 (Public Law 109-58) was signed into law. The act promotes investments in energy conservation and efficiency, including provisions for promoting residential efficiency, reducing Federal government energy usage, modernizing domestic energy infrastructure, diversifying the nation's energy supply with renewable sources (including biomass energy), and supporting energy-efficient vehicles. Introduction of national policies, such as Energy Independence and Security Act (EISA) in 2007 or proposal of national renewable energy standard for electric production can expand wood use in the United States for liquid fuel production, electric power production, and thermal energy production in the near future. The Energy Information Administration (EIA), predicts that between 2005 and 2030 electricity demand in the Southeastern demand region will increase at an annual rate of 1.5% (EIA, 2007).

According to DSIRE (2010), twenty-nine states and the District of Columbia had enacted Renewable Portfolio Standards (RPS) mandating that portion of electricity come from renewable sources, while six other states had put in place renewable energy goals (DSIRE, 2010). Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) strongly support biomass fuels and products mainly to reduce oil and gas imports. Nowadays, in the United States of America biomass is the largest source of renewable energy and provides over three percent of total energy consumption.

The Biomass R&D (Research and Development) Technical Advisory Committee (panel established by the U.S. Congress) predicts to achieve 30 percent replacement of the current U.S. petroleum consumption with biofuels by 2030 (Perlack et al., 2005). To reach this goal one billion dry tons of biomass feedstock per year is needed. It is estimated that 64 million dry tons of residue would come from forest logging and site clearing operations, and 60 million dry tons of biomass would come from fuel treatment operations. According to the report, these amounts are sustainable from forestlands in the contiguous United States on an annual basis. The report written by Perlack et al. (2005), determines if the U.S land resources are able to produce such amount of sustainable supply of biomass. According to the authors, agricultural potential and capacity is almost three times bigger than biomass derived from wood in spite of higher forestland area. It is mainly caused by the level of management intensity. Forests are managed mainly extensively because of their additional ecological and social services such as wildlife habitats, biodiversity, water protection etc. Agriculture is mainly managed intensively to get the biggest possible yield from every hectare of land. Perlack et al. (2005) study focused on the technology and infrastructure required to meet the targets, not the economics of the bioenergy markets.

The forest market review 2009-2010 indicates that European imports of wood energy have continued to grow. North America accounted for a large part of this growth, in particular southeastern U.S. became a key wood energy exporter to Europe in 2009. In the same time, Canada, another major forest biomass operator has been developing the wood fuel sector and pellets export. British Columbia and eastern part of Canada became important strategic points in pellet production.

Current predictions on North America energy sector emphasize increased domestic use of wood energy in both Canada and the US. In spite of increasing domestic utilization of wood energy in these countries, the export orientation of the North American wood fuel sector continues to grow in importance. One of the main reasons of continuing the trade partnership can be discrepancies in public policies between the two sides of the North Atlantic (Forest products annual market review 2009-2010, 2010). Moreover, Gan and Smith (2006) indicate that Southeast and South Central regions of United States with their relatively high spatial distribution density of logging residues are favorable places for commercial development of biomass-fueled power plants (Gan and Smith, 2006). Currently we can observe not only development of biomass fueled power plants in the Southeastern U.S but also fast investments in pellet plants done by European Union countries such as Germany and Sweden.

Figure 3 below depicts the dominant position of North America in pellet exports to the EU. Between 2009 and 2010 North America increased pellets delivery at the expense of Asia.

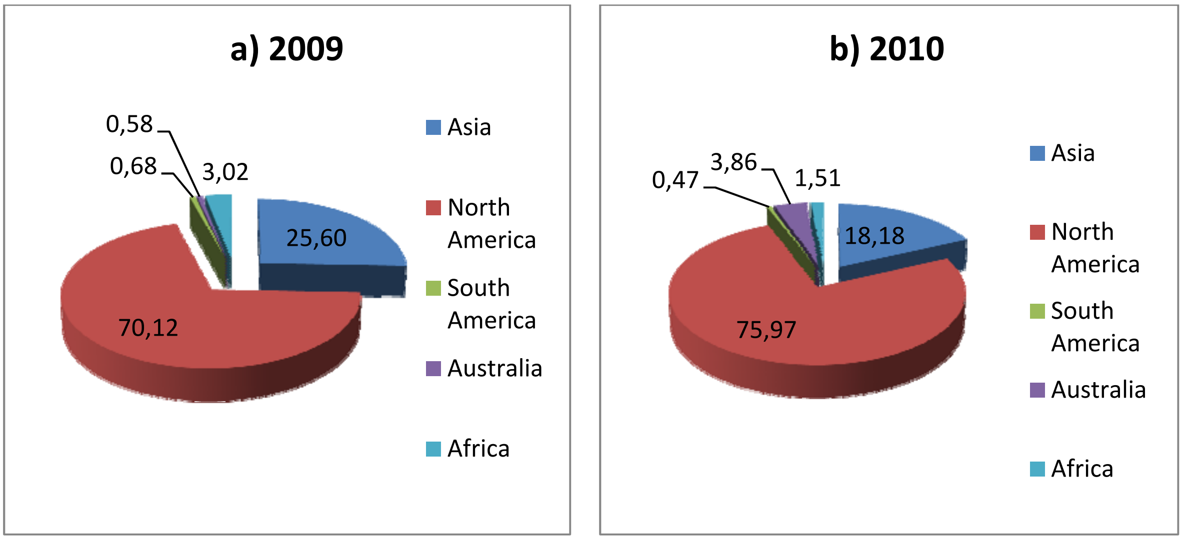


Figure 3. Import of pellets from third countries to the EU-27 in 2009 (a) and 2010 (b). (Source: Eurostat)

Wood pellets: characteristics, current market conditions, and future potential

According to Ekstrom (2011), a number of new wood pellets plants in the U.S. and Canada are set to commence operations during 2011, with more plants planned in the coming years. The industry in U.S. and Canada is eyeing the growing demand in four regions: Europe, Asia and to a lesser extent the Maritime Provinces of Eastern Canada and Northeastern U.S. (Ekstrom, 2011). Green Circle Bio Energy Incorporated (owned by Swedish company - JCE Group AB) is building the world's largest wood pellets plant in

Cottondale (Florida). These wood pellets will be exported to a handful of European power companies. The plant in question is scaled to produce 550,000 tons of wood pellets per year from regionally sourced pulp-quality southern yellow pine roundwood, produced in abundance in the Southeastern U.S. (Kotrba, 2011).

Present wood pellets consumption for energy in the EU is around ten million tons, (0.2% of gross final energy consumption (GEC)) while the total wood and wood waste consumption (taking into account pellets) is about 170 million tons (3.9%) (Sikkema et al., 2011). Sikkema et al. (2011), indicate that wood pellets demand is growing across Europe, while wood pellet production capacities are still largely unused. Low energy conversion efficiency of traditional use of wood (sometimes as low as 10%) and considerable emissions (dust, soot) caused the technology development which led to the application of strongly improved heating systems. Interestingly, advanced domestic heaters can obtain efficiencies of 70-90% with strongly reduced emissions (Faaij, 2006). Consequently, standardized fuels such as wood pellets have become important sources of renewable energy in the last years.

Pellets are perfectly suitable for commodity traded internationally and transported over long distance (Mantau et al., 2007). Processing of wood to charcoal, pellets or briquettes makes transportation more efficient as the energy value increases (Hillring, 2006). According to Junginger et al. (2008) wood pellets are one of most successful bioenergy-based commodities traded internationally. Compared to other solid biomass fuels, wood pellets are characterized by low moisture content and a relatively high heating value (about 17MJ/kg) which allows long-distance transport by ships without affecting the energy balance. Furthermore, wood pellets are relatively easy to handle during the process of transportation and can be stored over long periods without significant loss of dry matter. Research done by Suurs (2002) indicates that transport chains based on the transport of high density energy carriers, such as logs and pellets, are the most attractive while the transport of chips should be avoided categorically due to their low density and high production costs (Suurs, 2002).
Skytte et al. (2006), note two main reasons why refined wood fuels such as wood pellets or briquettes are the main commodities in international biomass trade. The first advantage, already cited, concerns the higher energy density compared to unprocessed products such as

wood waste and sawdust. The second reason concerns the circumstance that imports of untreated wood products is restricted in order not to spread pests and diseases (Skytte et al., 2006). Assuming a conversion factor of six cubic meters of sawdust for one ton of wood pellets (www.woodenergy.ie), it is striking how economically inefficient this transport of unprocessed wood products is especially on long distances.

Lack of contaminants (such as heavy metals) makes wood pellets environmentally friendly. According to Capaccioli and Vivarelli (2009), the largest reduction was shown for pellets substituting coal for power production (about 1.9 tons CO2 equivalent per ton pellets), followed by substitution of heating oil for district heating (about 1.5 tons) and natural gas for residential heating (about 900 kg). In 2006, in the EU countries plus Norway and Switzerland, ten million tons of CO2 equivalent emissions were avoided (Capaccioli and Vivarelli, 2009). This estimation is based on a consumption of six million tons of wood pellets, substituting for coal and heating oil. Rising heating oil prices made wood pellets competitive with fossil fuels (Junginger et al., 2008).

Figure 4 shows historical imports from USA to the EU (twenty-seven member countries) in terms of product code in thousands of tons.

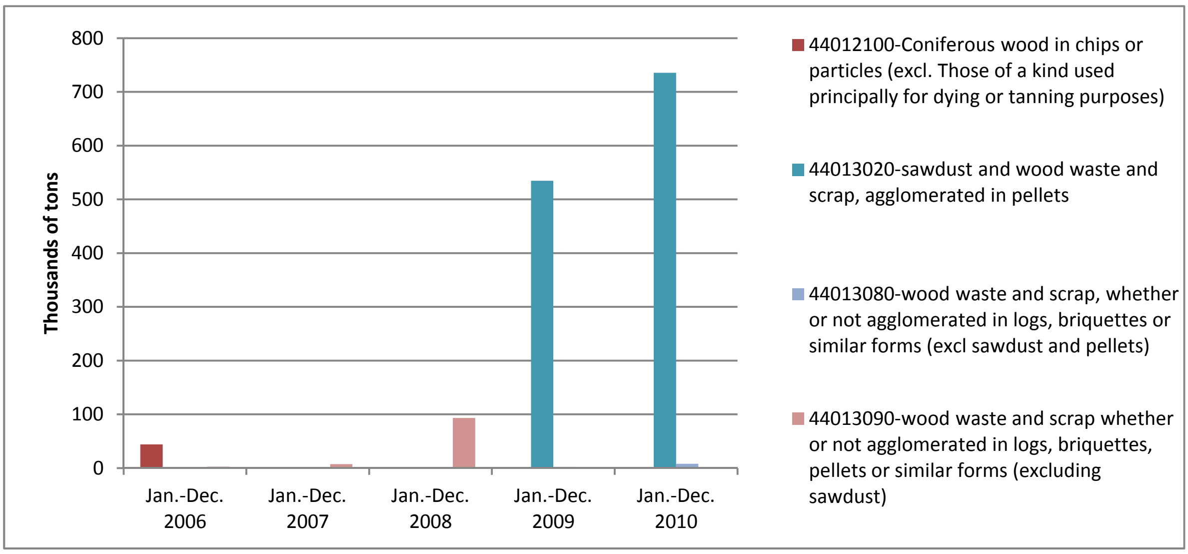


Figure 4. Historical import of biomass from United States of America to EU (27) in terms of product code in thousands of tons. (Source: Eurostat database)

Most notable is the product code 44013020: sawdust and wood waste and scrap, agglomerated in pellets. This code was created quite lately. Before pellets trade were recorded as code number 44013090 in Eurostat database as wood waste and scrap whether or not agglomerated in logs, briquettes, pellets or similar forms (excluding sawdust). United States International Trade Commission (USITC) still use the code 440130 and describes it as the same product as the code 44013090 in Eurostat database. This kind of discrepancies in product codes, the update in databases and complicated name of products categories create a big challenge to trace the biomass trade and confirm information between exporting countries and importing countries in terms of exact product and volume.

USITC database provides information that Belgium, Italy, Netherlands and United Kingdom were the largest in importers of product 440130 from the U.S. between 1996-2010 (Figure 5). In this period, Belgium, Netherlands and United Kingdom imported most of the volume the last three years (2007-2010) while Italy had imported huge amount of woody biomass in 2005, and after which the trade totally stopped (Figure 6). In 2010 Belgian imports of woody biomass from U.S. decreased dramatically, while it decreased slightly for Netherlands and showed a rapid increase in the UK. The main factor behind these changes is hard to pin-point but the economic situation in general, change in sourcing of wood pellets, or development of other renewable energy sources are potential determinants.

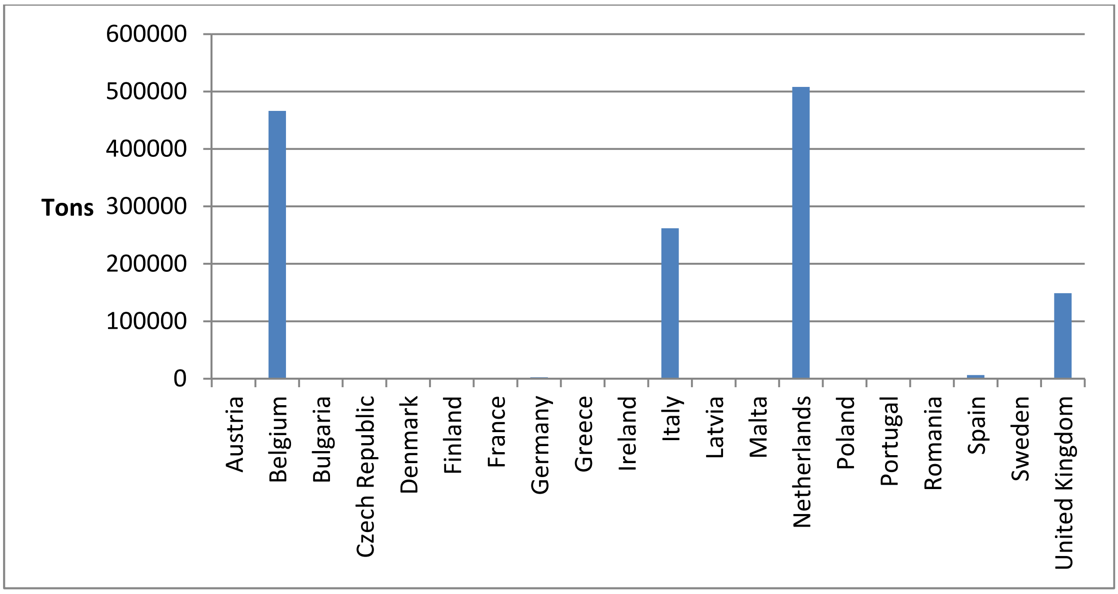


Figure 5. Wood biomass export (tons) from US to EU-27 between 1996-2010
(Source: USITC)

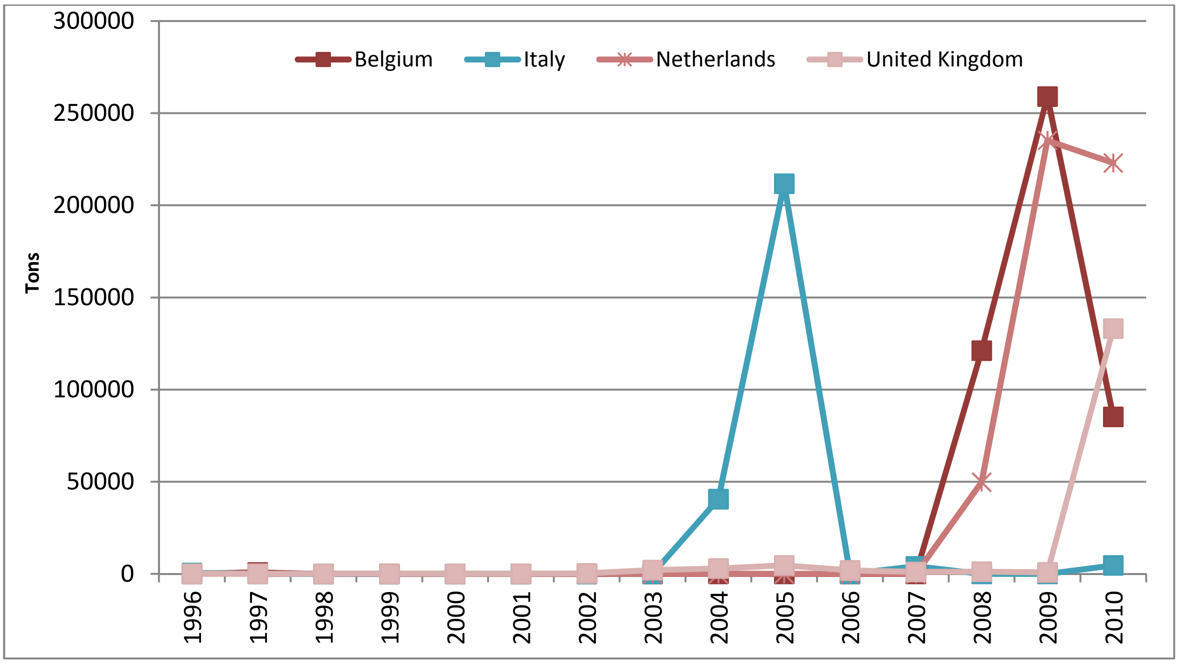


Figure 6. Wood biomass export from U.S. to EU-27 between 1996-2010 in thousands of kg (tons).
(Source: USITC)

In USITC database there is also a possibility to extract data about total traded volumes and its trend between 1996-2010 years (Figure 7). Decline of biomass export between 2009 and 2010 may be caused by global recession that was influential that time.

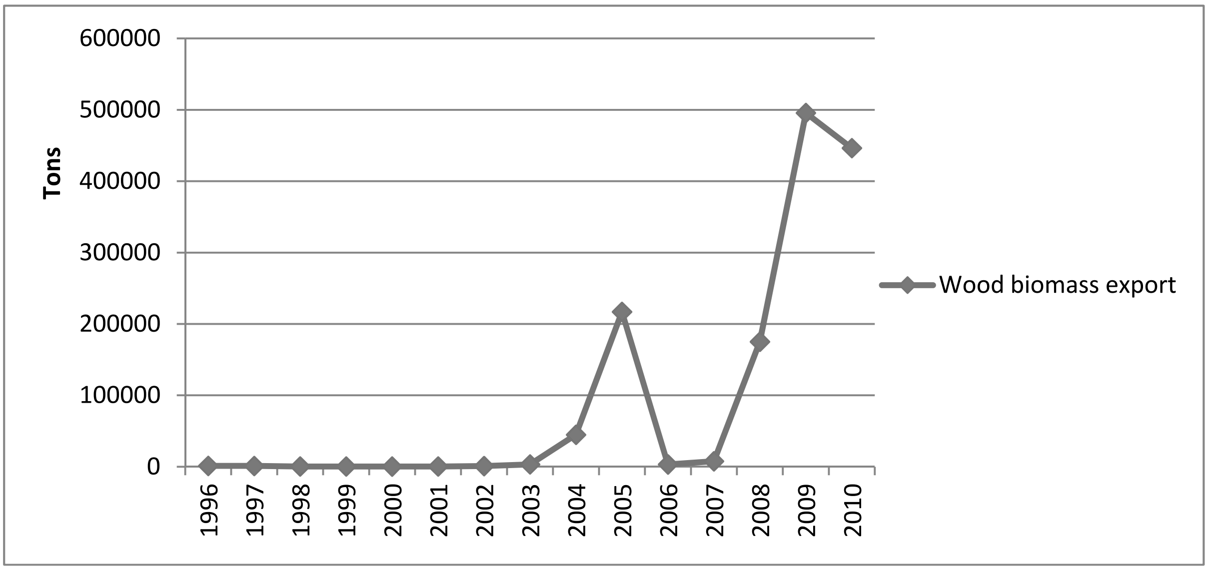


Figure 7. US wood biomass export between 1996-2010 in thousands of kg (tons)
(Source: USITC)

USITC provides also information which harbors in the USA exported woody biomass (440130) to EU-27. It is quite reasonable to predict that these harbors will still remain as the main harbors that will export pellets in the future to EU. All of the harbors that exported woody biomass to European Union are located in the Southeastern U.S. Figure 8, shows the most important harbors, total volume exported (in tons) and percent of total exported volume in 2009 and 2010.

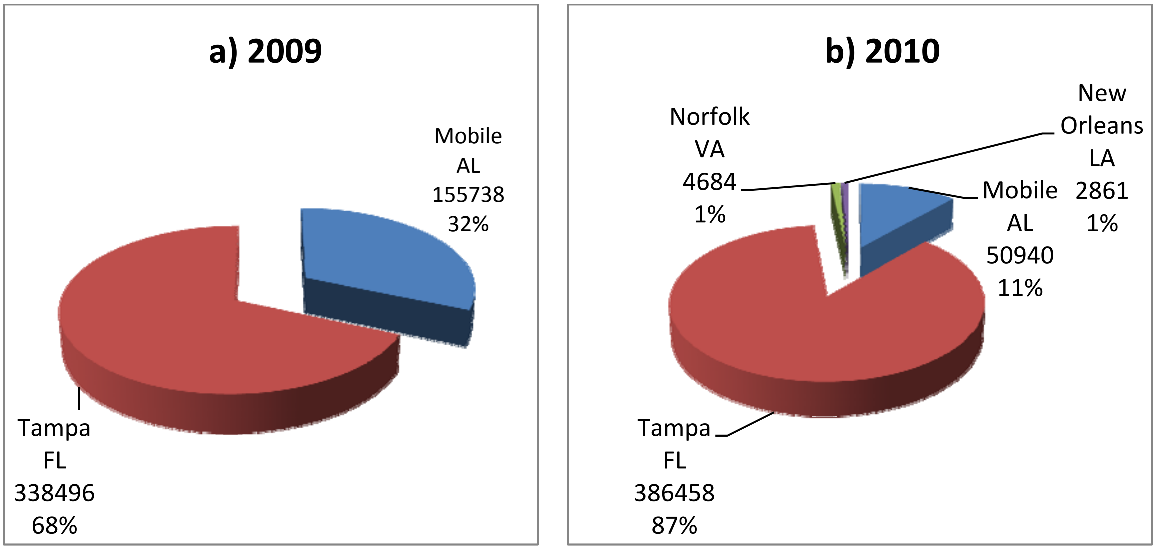


Figure 8. Export of sawdust and wood waste and scrap, agglomerated into pellets (code 440130) to EU-27 in 2009 (a) and 2010 (b).
(Source: USITC)

The main harbors are: Tampa (located in Florida) and Mobile (located in Alabama) which together export almost 100% of total woody biomass to European Union. Generally, U.S. South stands for 99.8% of total export of 440130 to EU-27 (USITC). Due to fast pellet infrastructure development in the Southeast, the number of well accommodated harbors that can handle pellet logistics will increase.

In 2006, Sweden, USA and Canada were the world's largest producers of pellets, with an annual production capacity exceeding 3.5 million tons (Peksa-Blanchard et al., 2007). Sweden is one of the largest pellets markets and is expected to keep this position, at least in the short term. Other large markets include Austria, Belgium, Denmark, Germany Italy and the Netherlands, Denmark and Belgium. A second group of major pellet producers in 2006 is composed of countries with production ranging from 200 000 to 600 000 tons. This latter group includes Estonia, Latvia, Russia, and Poland (Peksa-Blanchard et al., 2007).

Countries such as Austria, Germany, Latvia and Poland exports a large share of their wood pellets production, while countries such as Denmark, Netherland and Belgium are major wood pellets importers in the EU (Sikkema et al., 2011). Some markets are mostly driven by export potential opportunities: the Baltic States (Estonia, Latvia, and Lithuania), Finland, Russia, Poland, Canada and recently also United States of America. The Russian Federation has the potential to become one of the largest wood pellets markets in the world, provided a proper regulatory framework is in place.

Under the Kyoto Protocol the use of biomass for energy production gives credit to the user, not to the producer of the fuel. Hence, Denmark, Italy, Sweden and other industrialized countries have a strong incentive to import wood pellets (Peksa-Blanchard et al., 2007). In most of the European countries, pellets industries are still small consumers of wood fibers. Imports of wood pellets seem likely to develop quite rapidly in coming years, judging by growing production volumes in North America and North-west Russia: countries which are regarded as the main sources of industrial pellets from regions outside the EU.

According to Mantau et al. (2007), many European countries have much higher proportion of wood use for energy than recorded in official statistics. Wood volume for energy generation can represent around forty-two percent or 333 million m3 (EU27) and 343 million m3 (EU/EFTA) of total available wood volume (Mantau et al., 2007).

Assessing the growing trade in wood pellets is hampered by the lack of detailed trade and production statistics. There is no single source for wood-fuel statistics at the global level. Fortunately, there is a possibility to estimate volumes and trade patterns by using the connections to forest-products trade. Presently the biggest obstacle of biomass trade is the lack of a well-developed infrastructure and the still rather inefficient technology for obtaining bioenergy from woody biomass (Hillring, 2006). These two factors result in a presently relative high bioenergy price, and there is no incentive for the industry and average citizens to change the source of energy. In the coming years this will probably change, most likely as a result of technological progress. We should also bear in mind that the renewable energy policy has been closely tight to oil prices.

EXISTING BIOMASS MODELS

Since the SubRegional Timber Supply (henceforth SRTS) model (used in this thesis) is a part of group of bioeconomic models that include the forest resource base, I would like to give a brief summary about major models and how SRTS fits into this area. I would like to concentrate on models that currently describe and project biomass demand, supply, and availability. Forest sector models that integrate dynamics of forest resources, timber supply, forest industry, and forest product market demand are taken into account. The short characterizations of the models will include: model type (gap, market, etc.), applied region, basic assumptions, and possible results. All models were grouped into two main categories: models are applied to global and local level respectively. Two models (FASOM and ENFA) able to join forest and agriculture sectors together are included. At the local level, only North America and Europe were taken into consideration.

Global scale

The Global Forest Product Model (GFPM) is an economic model that models global production, consumption, trade and prices in fourteen principal categories of forest products for 180 individual countries ((Buongiorno et al. 2003; Raunikar et al. 2010). Detailed information about the model can be found in Buongiorno et al. (2003), Turner et al., (2006) and Raunikar et al. (2010). The GFPM model can be described as a recursive, dynamic, spatial, and market equilibrium model that represents supplies in each country of wood and non-wood fiber raw materials. Fiber raw materials include roundwood, sawnwood (lumber), recovered paper, production of intermediate wood pulp products, plywood, particleboards, fiberboards, newsprint, printing and writing paper, paperboards and fuelwood.

The European Forest Institute Global Trade Model (EFI-GTM) is a global, partial equilibrium, forest sector model. It is a multi-regional and, multi-periodic forest sector model that integrates forestry, forest industries, final forest industry product demand and international trade in forest products (Kallio et al., 2004).Currently the model includes 61 regions, in the whole world. The main geographical focus of the model is Europe (Solberg et al., 2007). EFI-GTM can model six wood categories, 26 forest industry products and 4 recycled paper grades. The model is able to calculate periodical production, consumption, import and export quantities. Moreover EFI-GTM calculates product prices for the forest sector products and periodic capacity investments of the forest industry for each region (Kallio et al., 2004). EFI-GTM was used to analyze the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries (Moiseyev, Solberg et al., 2011).

Local scale

The United States Forest Products Module (USFPM) was developed within the general Global Forest Products Model (GFPM) (Ince and Buongiorno 2007). USFPM provides more detailed analysis of regional U.S. timber supply, timber markets and wood energy markets within the context of global forest product markets. Moreover, timber harvests by species group and timber product outputs are tracked also in greater detail than global model. The USFPM module is able to solve a global spatial market equilibrium problem for selected years at periodic intervals over a multi-decadal time frame. The module can simulate dynamic changes in supplies, demands, input coefficients and costs from period to period (Ince et al., 2011).

Wood Resource Balance is a gap model that brings together in structured format all parts of supply and demand of wood. The model was used in the EUwood project where historical balances were made for 2005 and 2007 and projected balances for 2010, 2020 and 2030. For detailed descriptions of EUwood project and Wood Resource Balance, see Mantau et al. (2010a; 2010b). Currently the model is applied to the European Union woody biomass market, but its structure allows estimation at global scale as well. The Wood Resource Balance can in easy way integrate cross-sectoral information that is going far beyond existing trade and production classifications of the forest based sector. One of the main targets of Wood Resource Balance is to close the gap that is created by partial and not fully completed statistical data of supply and demand of raw materials. The model can calculate the balance based on the differentiated structure of markets and trade flows, and thereby quickly uncover missing information in the spreadsheet (Mantau et al., 2010b). Furthermore, the model integrates information and developments from the forestry and energy sector and functions as a tool to control all wood flows on national and international level.

The SAFIRE model is an equilibrium model that balances expected market demand for energy with a set of conventional and renewable supply options (Siemons et al. 2004). The model uses economic payback criteria and extensive user-entered data on prices and other installed capacities. This kind of data is employed to create various scenarios for technical potential, market potential and market penetration for renewable energy technologies. The SAFIRE model uses different scenarios to test for example the capital cost of applications, the biomass fuel cost and the value of sustainability premium. Generally the SAFIRE model was used in differentiated manner in energy sector within European Union. Mainly electricity sector, heat sector and biofuels in the transportation sector were applying SAFIRE model approach. Siemons et al. (2004) provided reliable and accurate data on contribution by bioenergy to the EU energy market by 2010 and 2020, mostly by taking various policy instruments into account. Economic investment behavior in the future can be modeled by the SAFIRE model and it is dependent on many external parameters. For example Siemons et al. 2004 were analyzing the influence of parameters such as: the value of sustainability premium and the presence or absence of subsidies on investments in biomass fuel conversion technologies.

The ADMIRE REBUS model is a dynamic market simulation model. The model provides a dynamical simulation of the development of the EU renewable electricity market and gives an insight in this developing market to the investors in renewable capacity (Uyterlinde et al., 2003). The ADMIRE REBUS was built for analyzing the effects of different support policies in the EU Member States for the deployment of Renewable energy sources (RES-E) technologies. The model is based on an extensive dataset containing the resource potential and costs of different RES-E technologies in Member States within EU (Skytte et al., 2006). One of the main problems of the model is the variety of institutional settings present in the current EU renewable electricity market that may cause trade barriers and distortions in the near future. As the model for the simulation of the developing market, the ADMIRE REBUS model is able to describe both the current situation and the most conceivable future situations. Lastly, ADMIRE REBUS model can incorporate the influence on RES-E investor behavior of the risks inevitably arising from any market in transition (Uyterlinde et al., 2003).

The GREEN-X computer model was developed along the same lines as the ADMIRE REBUS model. The GREEN-X model was implemented between 2002 and 2004 and allowed the simulation, comparison and analysis of the interactions between RES-E, Combined Heat and Power (CHP), Demand Side Management (DSM) activities and Greenhouse Gas (GHG) reduction within the liberalized electricity sector, both for the EU as a whole and individual EU 15 Member States (model was planned to extend the geographical target region for new EU Member States in the future) (Huber et al. 2004). One of the main advantages of the GREEN-X simulation tools is that the user can change policy and parameter settings within simulation run. Each country can be modeled individually. The GREEN-X model calculated that total import of forestry biomass from abroad was 2.6 Mtoe in 2005 (European Commission- EC, 2009). According to model there are predictions that import will increase to 3.8 and 8.7 Million tons of oil equivalent (Mtoe) of primary energy in 2010 and 2020, respectively. Moreover, the price of the imported biomass is projected to increase from 4.6 euro per Giga Joule (GJ) in 2005, to 5.9 and 7.1 euro per GJ in 2010 and 2020, respectively (European Commission- EC,2009).

The SRTS model is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations. The model uses inventory and harvest to model price consequences and development of inventories, given exogenous assumptions about land area and demand. Moreover, the SRTS model provides a simple simulation environment for examining timber supply issues and assumes that price is determined by the interaction of supply and demand in the aggregate market. More detailed information about SRTS model can be found in the methodology chapter.

One of the models that include combined forest and agriculture sector is FASOM (Forest and Agriculture Sector Optimization Model) (Solberg et al., 2007). At the beginning the model was developed for agricultural uses (ASM- Agriculture Sector Model) for United States, next the greenhouse gas emissions (GHG) from agriculture were incorporated (ASMGHG). Finally, model was developed for U.S. Environmental Protection Agency (EPA) and took into account forest sector (FASOM). The main purpose of the model is to evaluate the welfare and market impacts of alternative policies for carbon sequestration by forestry and agricultural land use in a long-term prospective. In 2002-2003 FASOM was adapted to EU conditions, resulting in the model EU-FASOM. All these models have as a target to make possible consistent analysis of abatement cost curves for GHG emissions, and how changing policies, technologies and market conditions influence these costs (Solberg et al., 2007). EU-FASOM can be described as a regional, multi-periodic, intertemporal partial equilibrium model depicting land transfers and other resource allocations between and within agricultural and forest sectors. No applications of the model are published at present.

The next model that is able to connect forest and agricultural sector is the ENFA (European Non-food Agriculture model). It is a dynamic, market equilibrium agricultural and forest sector model based on welfare optimization. The model integrates economic and environmental assessment of non-food alternatives in European agriculture and forestry (Solberg et al., 2007). The main purpose of ENFA is to analyze market and environmental impact of non-food biomass use under changing policies, technologies and market conditions. One of the advantages of the model is the possibility to analyze the environmental impacts (such as GHG, water quality, biodiversity and soil erosion), farm welfare, labor demand and land values. The model was developed by Hamburg University in Germany. Solberg et al. (2007) did the comparative evaluation of existing international economic models of the forest sector, the agricultural sector and the energy sector, and concluded that none of the existing models are capable of performing good analyses of international trade of biomass and bioenergy products (Solberg et al., 2007). All forest sector models described above were included in Solberg et al. (2007) study. The authors mentioned that combination of models is necessary in the close future.

METHODOLOGY

SRTS model description, data and assumptions

In this Master thesis, the SubRegional Timber Supply (SRTS) model was used to model the existing and projected market situation (price, inventories, supply, and harvest) and carbon storage under different hypothetical demand scenarios. Every scenario consists of two main components: EU wood pellets consumption and U.S. domestic wood fuel feedstock consumption. SRTS combines economic resource allocation with biological growth to link timber markets (including price and harvest) with forest resource dynamics. Moreover the model simulates the impact of market demand assumptions on the sub-regional, ownership, and forest type components of the supply side of the market (Abt & Abt, in review). SRTS is a simulation tool that allows the user to examine the potential impact of different demand and supply assumptions on market and resource futures.

The SRTS model is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations. Initially the SRTS was developed to provide an economic overlay to timber supply models (Abt, 1989). The model uses inventory and harvest to model price consequences and inventory developments, given exogenous assumptions about land area and demand. The framework for projecting forest inventory is summarized in Abt et al. (2000). The SRTS model is able to project future timber inventories, estimate regional shifts, and compute price impacts at a substate level. The model can examine how different initial timber inventories, harvest patterns, and market characteristics affect future timber conditions and prices. The SRTS allows easy change of assumptions and easy examination of the results. The model has been used in many studies. (Pattanayak et. al 2002, 2005) used SRTS model to explore the influence of non-market values on timber market decisions by non-industrial private forest landowners. Prestemon and Abt (2002) used the SRTS model to project timber supply in the Southern Forest Resource Assessment, and Schaberg et al. (2005) applied SRTS to analyze the impacts of wood chip mills on timber supply in North Carolina. The latest extensions of SRTS model allow detailed analysis and user-defined product categories on a smaller area, such as a survey unit, and also include the impact of land use change. More detailed description of the updated SRTS model can be found in Abt et al. (2009).

To project timber supply trends based on present conditions and the economic responses in timber markets, the SRTS model uses U.S. Forest Service, Forest Inventory and Analysis (FIA) (US Department of Agriculture Forest Service, 2011) dataset of inventory, growth, removals, and acreage by forest type, private ownership category, species group, and age class for multi-county areas. FIA data are the key biological forest resource drivers for the inventory by forest management type, age class and species groups (Abt et al., 2009). This kind of data is collected annually in all states in the South and can be obtained from the USDA Forest Service by request, or can be found through the FIA website (USDA Forest Service 2009). The SRTS model provides a simple simulation environment for examining timber supply issues and assumes that price is determined by the interaction of supply and demand in the aggregate market. It is important to mention that in the SRTS, the potential price consequences, sub-regional harvest shifts, and inventory impacts from a harvest scenario are modeled consistently. One of the key assumptions of the SRTS model is a constant elasticity. Supply-price elasticity and the supply-inventory elasticity are required to determine the supply curve. Studies by Murray (1995) and Pattanayak (2002) indicate that supply and demand price responses are inelastic.

Demand-price elasticity is affecting the size of estimated shift and can be specified by the user. Supply parameters and an inventory shift allow the determination of the location of the supply curve, which, together with knowledge of the harvest level permits the calculation of the price. The model determines the price consequences of a given harvest and supply shift due to inventory changes. Hence, the inputs to the SRTS model include the elasticities and an aggregate harvest projection for the region, while outputs consist of a price projection and a harvest allocation among ownerships/regions.

Harvest across management types and an age class is allocated in the goal program that is receiving the projected target removals mix. Next, harvest is passed on to the biological accounting module. Additionally, inventory is adjusted from the starting inventory by subregion, owner, species, forest type and five year age class by adding net growth and subtracting the harvest estimated form the market equilibrium, thus allowing the updating of the inventory for the next period's equilibrium calculation. Inventory that is grouped into five southern forest types (pine plantations, natural pine, oak-pine, upland hardwoods and bottomland hardwoods) in two ownership classes (corporate and other private), and by five year age classes is tracked by the accounting module. Hardie et al.'s (2001) land use model is used to determine timberland acreage. The SRTS model includes county level demographic forecast that drives the urban-rural transition (Abt &. Abt, in review).

Several assumptions are made in SRTS model when assessing the impact of woody bioenergy demand on timber markets such as: logging residues are utilized first before any roundwood and woody bioenergy demand is perfectly inelastic. Detailed description of these two assumptions can be found in Abt K. et al. (2011).

Modelling assumptions

Elasticities and price

In this analysis, I assumed and used -0.5 and 0.5 for the elasticity of demand and supply respectively with respect to price, and 1.0 inventory elasticity for all of the products. A function of stumpage price and a non-specified demand shifter (assumed to be one) are needed to model the demand. Furthermore, product supply is a function of product stumpage price and inventory, with supply-price elasticity by product and owner set at 0.5 and supply inventory responsiveness for all owners set at 1.0 (R. Abt and K. Abt, in review). A supply-inventory elasticity of 1 implies that the supply curve shifts proportionately to changes in inventory.

Every scenario in this Master thesis assumes that traditional wood demands for the selected wood products categories, bioenergy demands and potential supply responses are projected in constant dollars.

Geographical scope

Scenarios were developed based on two main components: European Union wood pellets import and U.S. wood fuel feedstock consumption. Both components (import of pellets in the EU and U.S domestic biomass consumption) are related to the South-eastern region of U.S. This study defines Southeastern United States as the region comprised of the states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia and Kentucky. The research area is presented in figure 9.

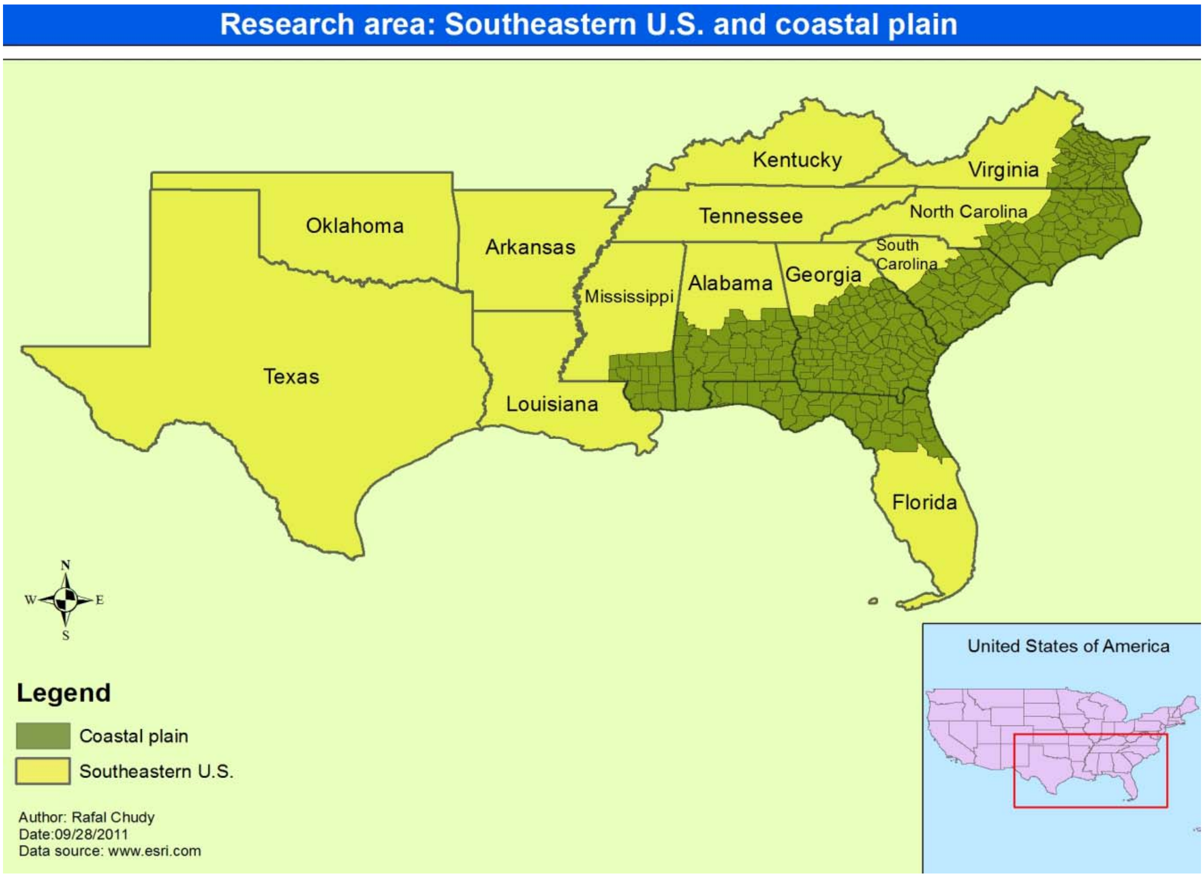


Figure 9. Research area: southeastern U.S. and coastal plain.

The SE states are the main focus of the SRTS model and its relationship to the regions as defined in the FIA database. The Southeastern U.S. has a large amount of forest resources available in this area and the potential for export of woody biomass to EU.

Species supply composition

One of my key assumptions is that 80% of the wood will come from softwood. Consequently only twenty percent of the quantity is assumed to come from hardwoods. According to Abt et al. (2011), harvest levels have historically been low in hardwood types across the South. This is mainly due to lower growth rates, restricted availability (steep slopes or wet soils, small tracts), and that landowners of these management types traditionally have had other objectives for owning their land in addition to or in place of profits from timber production (Abt et al., 2011).

After calculations of harvest composition, softwood contribute roughly 65% to total harvest in the Southeastern U.S. and 77% to total harvest on the coastal plain. My assumptions are biased towards softwood what can be explained by predicted higher demand of fast growing species devoted for biomass. Another reason is related to the assumption that wood pellets plants will use also higher proportion of softwood in pellet production process than hardwoods. Some recently established plants announce to use 100% softwood. My assumption takes into account slight change in pellet supply chain but also availability of resources in Southeastern U.S. and possible wood source diversification. Moreover, the need for forest certification may occur in the future. One should bear in mind that hardwoods are composed of many different species (as compared to one-species softwood plantations), which can influence woody biomass quality.

Harvesting residue rate and recovery rate

As far as the supply side is concerned, recovery rate and harvesting residue rate are the most important factors that decide how much of biomass can be extracted from the site. Briefly speaking, harvesting residue rate means how much of biomass will remain after cutting operations or in other words which part of total stand yield will be left on the ground after harvest. On the other hand, recovery rate means how much of remained biomass after harvest, can be extracted. In the literature there are different values for these two important rates. The biggest discrepancy in the studies is the relation between theoretical and practical rates for specific regions. Some authors simply forget that extraction of 90-100% of biomass can be possible in some sites but it is impossible to use them in whole regions, mostly because the huge variation in microhabitats, topography, species composition, management type, owner preference or ecological constraints. Currently the technology of biomass extraction is not a big problem but environmental conditions play a significant role. For example, marshes or mountainous areas significantly decrease biomass removals. In Southeastern U.S. there are the huge variations in forest conditions.

To simplify environmental variation, two values of harvesting residue rates were used. Division was done according to two forest types (coniferous and broadleaves) and is based on Forest Inventory and Analysis (FIA) data. According to FIA, the harvesting residue rate for coniferous stands is approx to twenty percent, while for broadleaves stands it amounts to forty percent of wood removals. The difference between the values for coniferous and broadleaves can be understood by the circumstances that after harvest operation in broadleaves stands, more branches, limbs and other woody parts will remain on the ground, compared to coniferous that have less branches and straights stems. We should remember that biomass as defined and reported by Forest Inventory and Analysis (FIA) is the aboveground dry weight of wood in the bole and limbs of live trees ≥ 1-inch diameter at breast height (d.b.h). According to FIA, tree foliage, seedlings and understory vegetation are excluded from above definition (Conner et al., 2004).

The assumption about recovery rate is derived from a study done by Jurevics (2010). The main objective of this study was to estimate optimistic and conservative ranges of available logging residues. In this study the value of 60% is considered as the most suitable in terms of residue availability and policy-based goals based on Jurevics (2011). Furthermore, removing residues can reduce the costs of site preparation and the risk of wildfire. Peter Ince et al. (2011) use the same recovery rate value (60%), which was the key to model U.S. wood fuel feedstock consumption in this thesis (Ince et al., 2011). According to Galik et al. (2009), not all residues are available for use. In their analysis about bioenergy potential and forest biomass supply in the Southeastern U.S., a technical recovery rate of 50% was assumed (Galik et al., 2009).

Stokes (1992), reported a wide range of recovery percentages, with an average of about 60% potential recovery behind conventional forest harvesting system (Stokes, 1992). A report by Wilkerson et al. (2008), indicates that with newer technology, it is estimated that current recovery is about 65%. Gan and Smith (2006), based on the 1997 Forest Inventory and Analysis (FIA) data, used a 70% residue recovery rate and a minimum viable power plant capacity of 10MW estimated annual recoverable logging residues in the USA equal to 13.9 million dry tons from growing stock and 36.2 million dry tons from both growing stock and other sources. The residue recovery rate (70%) comes from the study done by Wall and Nurni (2003). According to authors, most logging residues were located in the eastern USA. The Southeast and South Central regions accounted for approximately two-thirds of the national total from growing stock and about 50% of that from both growing stock and other sources (Gan and Smith, 2006).

Finally, empirical evidence suggests that a 60 % recovery rate of logging residue (volume recovered to roadside for chipping and transportation to mills) is realistic for harvesting operations using conventional equipment (Perlack et al., 2005). A study assessing the potential for biomass energy development in South Carolina, reflects the plausibility of this rate of recovery (Conner, Adams and Johnson, 2009). More studies are needed in the future to determine the recovery rate and its influence on sustainable delivery of biomass to wood industry.

Recession and rebound

All demand scenarios in this analysis account for the current recession by assuming a reduction in demand from 2008 to 2012 followed by rebound between 2012 and 2015. The rate of demand change between these particular years will be equal to thirty-three percent.

Recession and rebound will significantly influence the harvest level. This kind of recession is called "v-recession", with a sharp downward trend and sharp rebound, but without a long period at the lowest level. Figure 10 shows the baseline domestic demand trend.

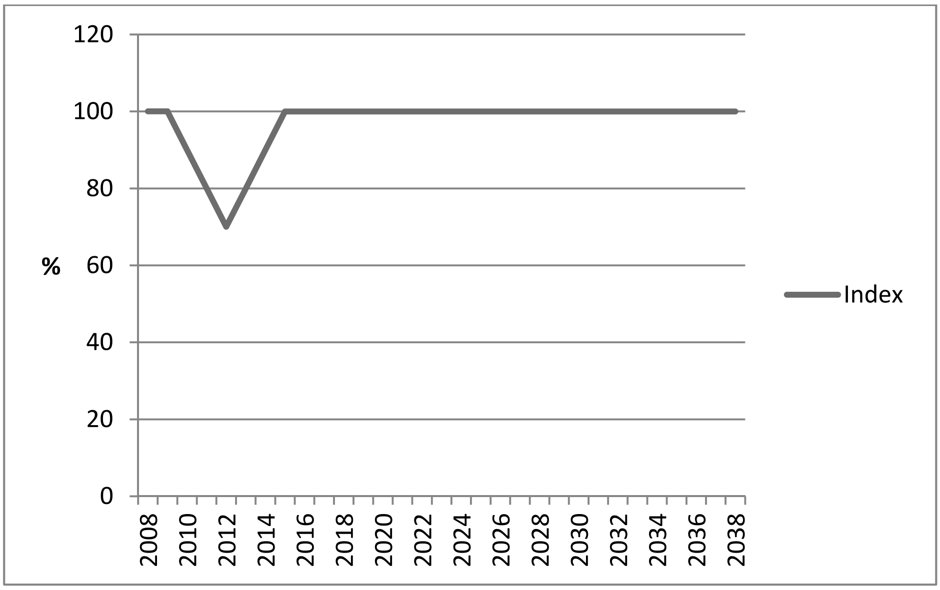


Figure 10. Baseline domestic demand trend with build in recession and rebound.

EU-27 pellet import from U.S.

Based on the literature review, it is concluded that wood pellets are the main bioenergy feedstock traded between North America and Europe. As total biomass consumption is predicted to increase in coming years, pellets are regarded as one of the important bioenergy commodities traded internationally that will contribute a significant share of total biomass consumption growth. Pellets demand in this study is based on Capaccioli and Vivarelli (2009). This report contains data about the European wood pellets market, and shows growing consumption up to 2020. The scenarios presented consider a very heterogeneous future for the pellets market.

The main assumptions used to model the European wood pellets market include: strong yearly development in pellet market up to 2011, normalization phase (up to 2013), difficulties for years 2013-2014-2015 and stabilization phase up to 2020. Yearly rate of increase, showing all these phases, can be observed in Appendix B. Following the authors, the demand for pellets in Europe will triple by 2020 in terms of volume. The main advantage of this report is the data about historic and predicted pellets production and consumption between 2006 and 2020. Subtraction of production from consumption allows us to determine predicted pellet import within the EU. Capaccioli and Vivarelli's (2009) projections only cover the period up to 2020. Continuation of the trend (six percent increase every year till 2038) was assumed. However, sensitivity analysis was done to see how changes in the pellets import trend can influence the market in the southeastern U.S. In this sensitivity analysis, two, four and six percent annual pellets imports increases respectively between 2020 and 2038 were assumed. The sensitivity analyses section in the result chapter describes the outcome of this variation. Figure 11 shows projection for pellets imports up to 2038 in the EU-27.

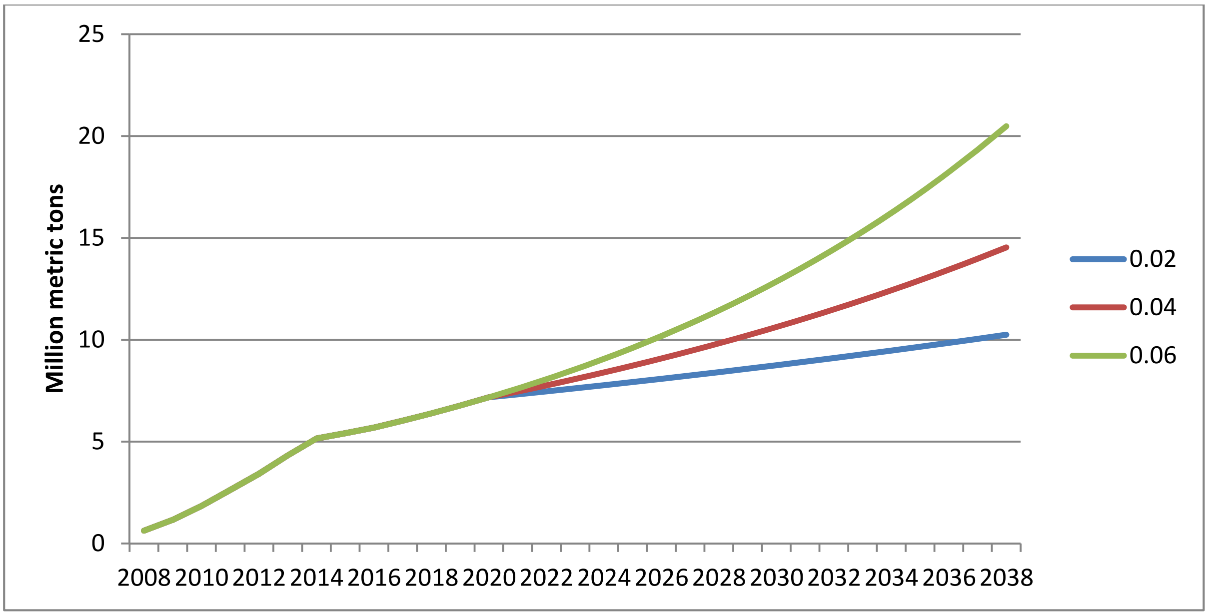


Figure 11. Imports of wood pellets (million metric tons) in the EU-27 between 2009 and 2038.

To determine how much of total EU pellets imports are sourced in the U.S, it is necessary to distinguish the percentage of U.S. pellet delivery. Based on the Eurostat database, results show that U.S. contributes between thirty to fifty-six percent of total imported wood pellets from third countries to EU-27. This discrepancy or range was caused because Eurostat provides two types of independent information about pellet import from third countries. First, source of information in Eurostat provided data about EU pellet import (in 100kg) from all third partner countries in the world. After division on countries that belong to European Union and countries that do not belong, percentage of U.S. pellet delivery was determined among countries from outside EU (around 30% for both 2009 and 2010). Second, this source contains data about EU total pellet import from third countries in thousands of cubic meters. After unit conversion and extraction of U.S. pellet tons export to EU, percentage of U.S. delivery was determined (around 56%). This result probably can be overestimated but it indicates and confirms that currently North America is considered as one of the most attractive regions in pellet export to the European Union. Of course we should bear in mind that next to U.S., Canada is also the main player in pellet industry across the Atlantic Ocean.

Assuming better transport position of the United States (shorter freight distance) compared to important in pellet production British Columbia in Canada, better growth conditions of Southeastern U.S. region and occurrence of homogenous, fast growing pine plantations, U.S. prevailing contribution of wood pellets to the EU can increase rapidly in coming years and can independently make the power of North America biomass export.

Based on the range in the data for U.S. pellets delivery to the European market (30-56%), a value of 40% was selected as representative. At the beginning of the study there was a plan to model three scenarios in terms of the EU pellet import from U.S., 30, 40 and 50 % respectively. Because of U.S. high wood fuel feedstock consumption range, described in the next chapter, the idea of diversification of percentage of U.S. pellet delivery to the EU for all scenarios was skipped. The second reason to abandon this idea was motivated by the fact that the results produced by SRTS model would not show significant difference with so small variation of pellet volume imported to the EU in the scenarios. However, sensitivity analysis was conducted for the medium U.S wood fuel feedstock consumption with all three values (30, 40 and 50%) of pellet delivery to EU market from U.S.

Another important factor taken into account during wood pellets import to EU is its moisture content. The most significant factor that relies on moisture is the amount of feedstock that is needed to produce one ton of pellets. Sikkema et al. (2010) analyzed three conversion factors that can be used to determine pellets moisture. These authors examined three different types of wood pellets (bulk pellets for district heating in Sweden, bagged pellets for residential heating in Italy, and bulk pellets for power production in the Netherlands). To produce one ton of bulk pellets (8% moisture content) for district heating in Sweden, around 2.12 tons of feedstock (average moisture content 55%) has to be taken. To produce one ton of bagged pellets (10% moisture content) for residential heating in Italy, around 1.78 tons of feedstock (average moisture content 47%) are needed. And finally, to produce one ton of bulk pellets for power production (6% moisture content) in the Netherlands, around 1.57 tons of feedstock (average moisture content 36%) has to be used (Sikkema et al., 2010). For all scenarios, 1.78 value was used to determine the amount of feedstock needed to produce one ton of wood pellet (moisture 10%). Sensitivity analysis was done using all conversion factors (1.57; 1.78; 2.12) for the medium scenario to find out the importance of pellet moisture content on natural resources and wood market in Southeastern United States.

Wood-pellet moisture standards

Estimation of pellets moisture content is important for determining the conversion factors of raw wood into pellets. In the United States, Pellets Fuel Institute (2010) determined that pellets mills are responsible for testing and certification of their product (PFI, 2010). Grbovic (2010), indicated that export-oriented pellet mills will also have to fulfill pellet standards determined by importing country or by common European standard CEN-14931 if implemented. Pichler (2009), did an analysis of development and situation in 2009 of pellet standardization and certification. In his overview of existing national standards for wood pellets in EU, moisture content is mostly represented by the upper threshold equal to

12%. A moisture of less than ten percent is required by most of the national standards specifications (Pichler, 2009).

Growth of EU bioenergy demand is influential on Southeastern forest resources but we should bear in mind that supply chain in wood-pellets production and required standards have to be considered in terms of production efficiency and forest resources impact. Pellets the same as other merchandise products has to be characterized by some kind of standard. Standards are very important in trade because thanks to them buyers and sellers can determine product quality and particular use. Moreover, standardization removes trade and application barriers by establishing unification (of concepts, procedures and products) (Pichler, 2009). Pichler (2009) underline that, standards increase economization, compatibility, user-friendliness and security in the application and exchange of products and services.

U.S. wood fuel feedstock consumption

Wood fuel feedstock consumption predictions for coming years in the United States of America are based on Ince et al. (2011). The United States is one of the many countries where national energy policies have been enacted. One of the most important, Energy Independence and Security Act (EISA) was introduced in 2007. This act and proposed legislation about national renewable energy goals for electric power can in the near future expand wood use dramatically for liquid fuel production, electric power production, and thermal energy production (Ince et al., 2011). Study and scenarios done by Ince et al. (2011), is using U.S. renewable energy projection from the 2010 U.S. Department of Energy Annual Energy Outlook (USDOE, 2010), which incorporates the impact of the U.S. Renewable Fuel Standard (under EISA), and authors also introduced hypothetical national renewable energy standard (RES) for electric power. Scenarios also include the recently enacted U.S. Renewable Fuels Standard (RFS) promoting use of biomass for expanded production of advanced biofuels (Ince et al., 2011). Important to mention is that scenarios were analyzed with U.S. Forest Products Module (USFPM) that was created to enhance the modeling of the

U.S. forest sector within the Global Forest Products Model (GFPM) and provides a more detailed representation of U.S. regional timber supply and wood residue markets.

Ince et al. (2011), describes four scenarios that were used to project market impacts of alternative policies that affect U.S. wood energy demand. Scenarios differ from one another mainly in terms of assumptions about future expansion in U.S. wood energy consumption through 2030. Full description of all scenarios can be found in Ince et al. (2011) and key economic assumptions of the four scenarios are summarized in Appendix C.

Generally, all scenarios include projected U.S. cellulosic biofuel output under the U.S Renewable Fuels Standard policy (RFS) as projected by the 2010 Annual Energy Outlook (AEO) (USDOE, 2010). The scenario labeled "HP" has a higher cellulosic biofuel demand projection from the AEO "High Oil Price" (HP) case, while the other three scenarios use the RFS biofuel projection from the AEO Reference Case. The authors provide information that all scenarios include additional biomass energy consumption under hypothetical national renewable energy standards (RESs) requiring either ten percent (RES 10) or twenty percent (RES 20) of electric power to be generated from non-hydro electric renewable energy sources by 2030. The last scenario, labeled "RES 20+EFF" includes a similar energy policy but allows half of the non-hydro renewable energy to be in the form of more efficient combined heat and power, therefore requiring somewhat less biomass input to attain the 20% renewable energy requirement (Ince et al., 2011). Figure 12 presents U.S. wood fuel feedstock consumption in million cubic meters with all four modeled scenarios.

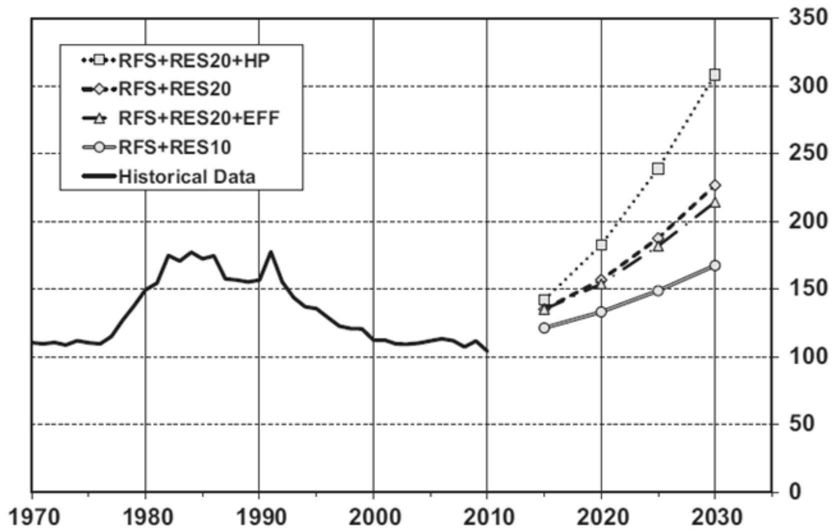


Figure 12. US wood fuel feedstock consumption (million cubic meters)
[Source: Ince (2011)]

In this thesis the four scenarios from Ince et al. (2011) were transformed into three scenarios. Scenarios RFS+RES 10 and RFS+RES20+HP have stayed without change while the average from scenarios RFS+RES20+EFF and RFS+RES20 was taken. Respectively these three scenarios are called A, B and C.

We should bear in mind that all these scenarios and data behind them are for the whole United States. To estimate what is the consumption in terms of wood fuel feedstock (total demands for all purposes: electricity, pellets, biofuels etc.) for Southeastern part of U.S., there is a need to determine the information how much Southeastern U.S. contribute to the total U.S. timber production. According to Smith et al. (2004), the South accounted for 63% of growing-stock removals in 2001, up from fifty-one percent in 1986. According to Forisk Consulting Company, the South contributes around fifty-one percent of total projected wood consumption in the USA (www.forisk.com). On the other hand Wear et al. (2002) and Loehle et al. (2009) provide information that Southeastern U.S. contributes around 60% of the whole US timber production (Wear et al., 2002; Loehle et al. 2009). Looking at the importance of Southeastern U.S. in exporting wood pellets to EU and high potential of this region in natural resources, the value of 60% was accepted as representative for Southeastern U.S. delivery in total U.S. wood feedstock consumption.

Modeled scenarios

Southeastern United States

Combined scenarios of EU-27 pellet import from U.S. and wood fuel feedstock consumption in Southeastern United States with main scenarios abbreviations are presented in Table 1. Scenarios based on Ince et al. (2011) paper were called A, B and C what with the combination with forty percent U.S. pellet delivery (of EU demand) to EU they are called now: A2, B2 and C2 respectively. Scenario A2 will be also quoted in the further text as 'Low', B2 as 'Medium' and C2 as 'High' scenario. Low, medium and high annotation applies also to the coastal plain, presented in separate chapter. In conclusion section comparison of Southeastern U.S. and its coastal region uses symbols to avoid confusion.

Scenarios such as A1, A3, B1, B3, C1, and C3 present different delivery percentages (one concerned thirty percent delivery and three concerned fifty percent delivery) and will not be highlighted in this analysis, but will be mentioned in one of the sensitivity analysis.

Table 1. Combined scenarios of EU-27 pellet import from U.S. and wood fuel feedstock consumption in Southeastern United States.

Label	U.S. domestic demand	% of US pellets delivery to EU
A2=Low	Low (RFS+RES10)	40
B2=Medium	Medium (Average of RFS+RES 20 and RFS+RES20+EFF)	40
C2=High	High (RFS+RES20+HP)	40

Figure 13 shows how projected scenarios of total wood fuel feedstock consumption in Southeastern U.S. look like between 2008 and 2038.

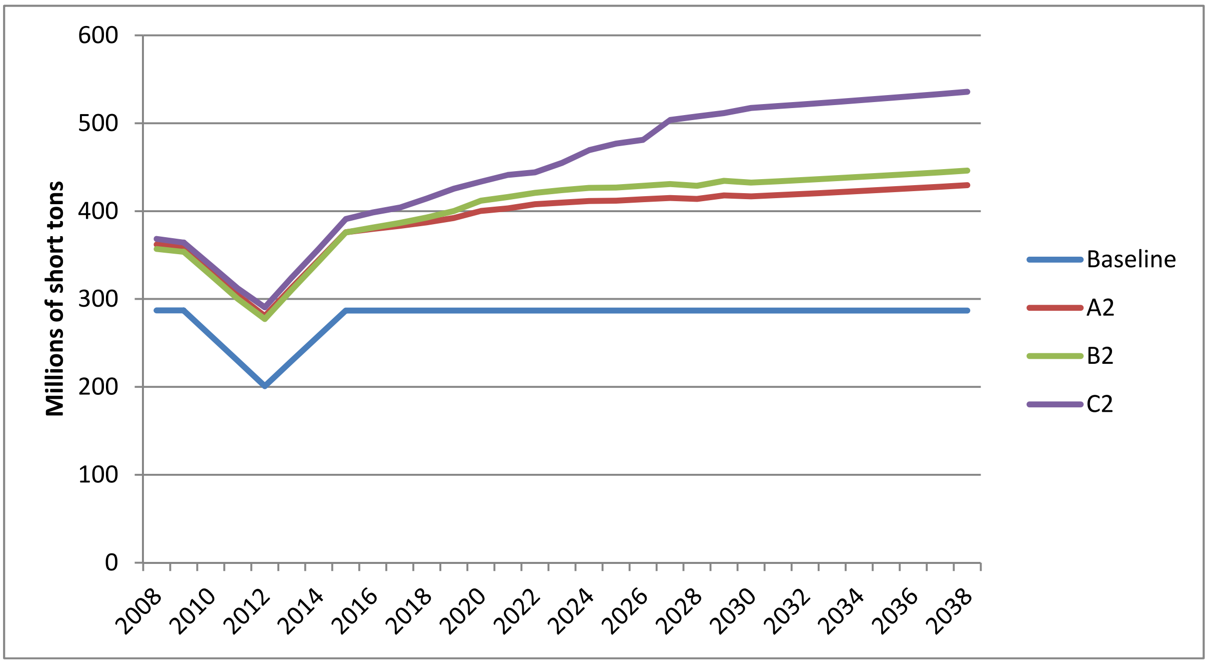


Figure 13. Combined scenarios of EU-27 pellet import from U.S. and wood fuel feedstock consumption in Southeastern U.S. between 2008 and 2038.

It is of interest to assess how much the Ince et al. (2011) model projections and estimation of future EU-27 pellets imports respectively contribute to total projected biomass consumption. Figure 14 presents the Ince et al. (2011) modeled consumption (marked as B2I) and total consumption (Ince et al. (2011) +EU-27 pellet consumption) for Southeastern U. S. only for the B2 scenario. The difference between these two lines shows the EU contribution to biomass consumption. Two other scenarios (A2 and C2) show very similar difference pattern. The Ince et al. (2011) model projections contributions to total projected biomass consumption are in the range from 88.7 % to 98.8% for all scenarios. This means that EU-27 pellets imports contributes from 1.2% (at the beginning of the projections) to 11.3% (at the end) for all scenarios.

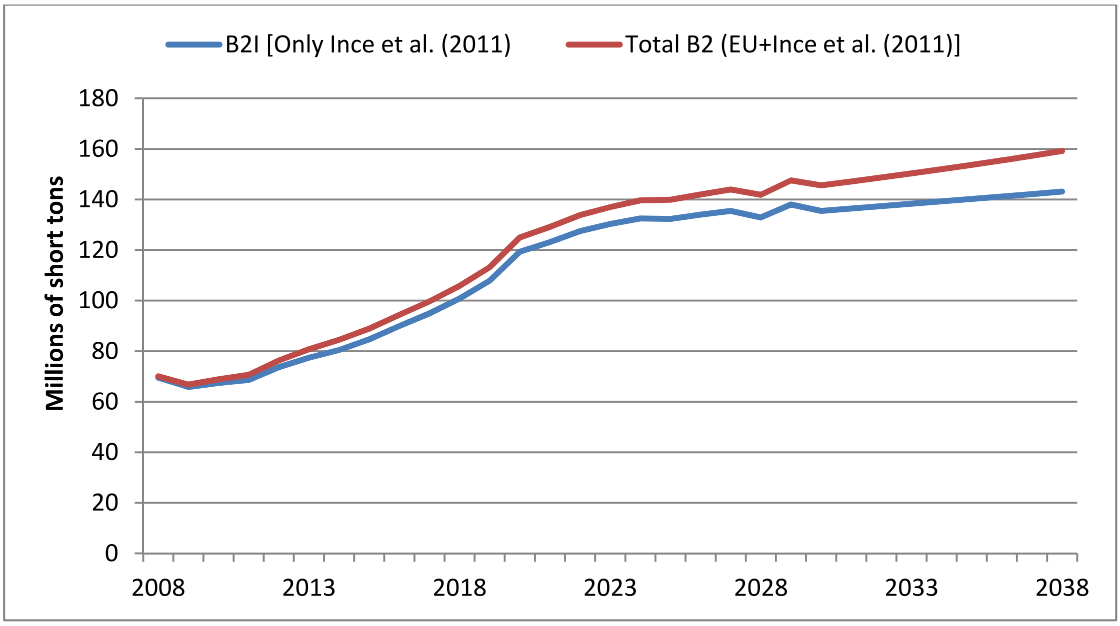


Figure 14. Additional consumptions contribution of Ince et al. (2011) projections and estimations of future EU-27 imports.

Sensitivity analyses

As mentioned before, for the Southeastern U.S. a sensitivity analysis of pellets percentage delivery from U.S. to EU-27 and moisture content were conducted. A sensitivity analysis of pellet delivery percentage was done for medium scenario (B) (Average of RFS+RES 20 and RFS+RES20+EFF). There are three assumptions of pellets import to EU-27 from U.S: thirty, forty and fifty percent respectively. Because this sensitivity analysis is included in B2 scenario, the abbreviations of modeled scenarios are: B1, B2 and B3. B2 scenario is exactly the same as presented in the Table 1.

Moisture content sensitivity analysis is included in B2 scenario and concerns different rates of feedstock conversion into pellets with specified moisture. The conversion factors used are: 1.57; 1.78 and 2.12. The three scenarios are in this instance denoted as: B2a, B2b, and B2c. Since the conversion factor 1.78 was used during the basic modeling, the scenario

B2b and B2 in the chart above are the identical. The results of the sensitivity analyses are presented as separate section in results chapter.

Southeastern U.S. - only coastal plain

Given the emphasis on exports and the concentration of corporate lands in the coastal plain, additional scenarios were developed assuming EU demand would be concentrated in the coastal plain. Analyzed region contains following States': North Carolina, South Carolina, Virginia, Georgia, Alabama, Florida and Mississippi. The scenarios include exactly the same assumption as for the whole Southeastern U.S. region. Scenarios for the coastal plain contain the letter "E" in the output graphs, what stands for "East" of the Southeastern United States of America.

An initial assumption was to split harvest based on inventory. Further analyses showed that harvest allocated for this region was much higher than based on inventory data. Mentioned States' located on the coast are covered mostly by pine plantations so supply of the wood in this particular area is relatively high. Assumed demand (23.6%) compared to whole Southeastern U.S. region was definitely underestimated. In fact most of the wood supply in the modeling of Southeastern region of United States came from the coast. Next, the data from SRTS was extracted to determine the division of Southeastern U.S. wood feedstock consumption (Ince et al., 2011) for all the States. After calculations, for all scenarios, percent value was very close to 35% for all years between 2008 and 2038 (see Appendix D). To summarize, 35% of Ince et al. (2011) wood feedstock consumption was used to determine domestic wood usage for the coast, plus whole EU pellet consumption was designated to come from the States located on the Southeastern U.S. coast.

Figure 15 presents how projected scenarios of total wood fuel feedstock consumption in Southeastern U.S. look like between 2009 and 2038. We can observe an increasing trend for all scenarios, and the slope of the lines is steeper than in the graph for whole Southeastern U.S. It is mainly caused by the fact that coastal States' of Southeastern U.S are mostly covered by pine plantations. Bringing back assumption that 80% of the wood to will come from softwood and only twenty percent from hardwoods to satisfy biomass demand explains well this situation.

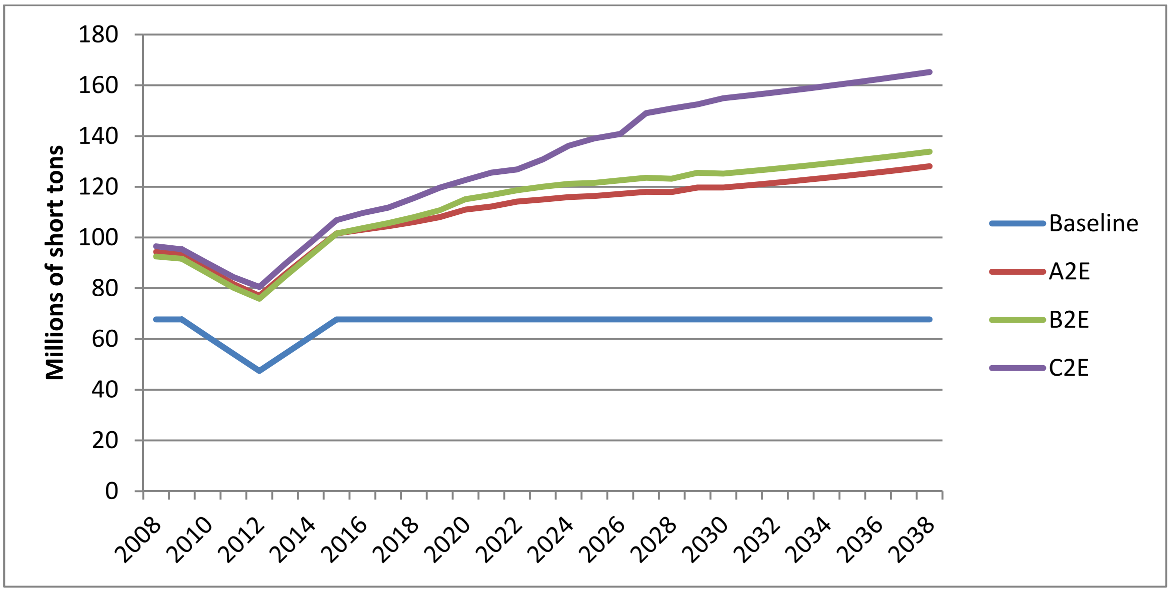


Figure 15. Combined scenarios of EU-27 pellet import from U.S. and wood fuel feedstock consumption on the coast of Southeastern U.S. between 2008 and 2038

Contribution of the Ince et al. (2011) model projections and estimations of future EU-27 pellets imports respectively for B2E scenario is presented in Figure 16. The results imply that pellets imports to EU-27 from Southeastern U.S. Atlantic coast are the more important. The B2EI abbreviation means that it is Ince et al. (2011) consumption contribution for East States' biomass consumption. Two other scenarios (A2 and C2) show very similar difference between the lines and Ince et al. (2011) consumption contribution to total biomass consumption is in the range between 73 % and 98% for all scenarios. It means that EU-27 pellet import contributes from 2 % (at the beginning of the projections) up 27% (at the end), looking at all scenarios.

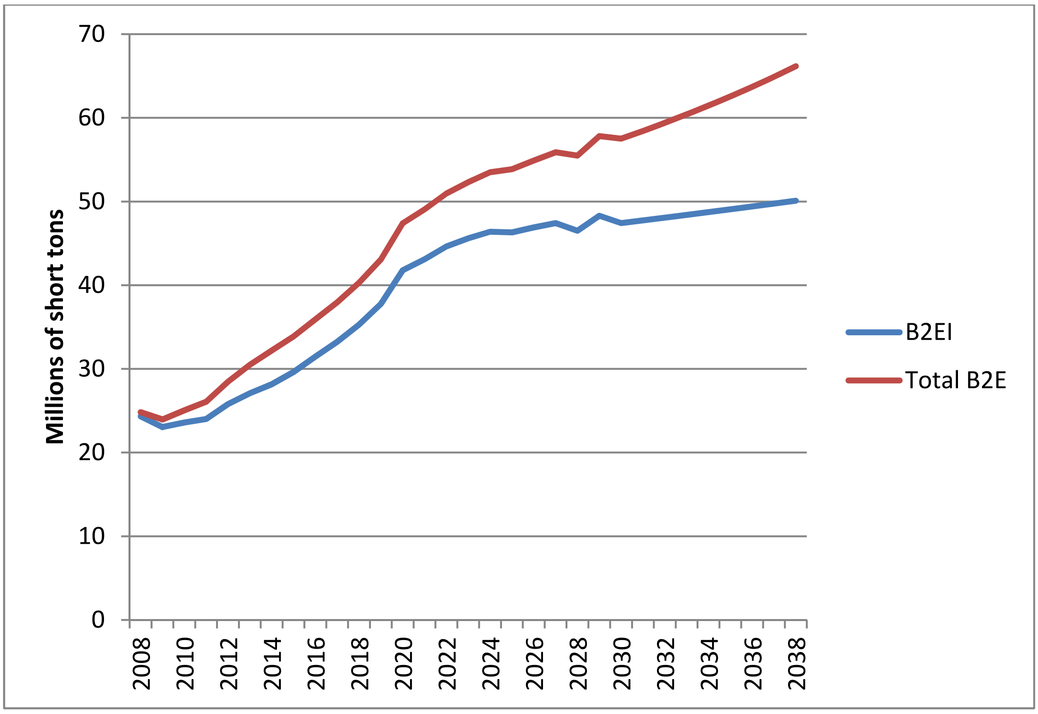


Figure 16. Additional consumption contribution of Ince et al. (2011) projections and EU-27 imports estimations for Southeastern U.S. coast States'.

RESULTS AND DISCUSSION

Southeastern U.S.

Description of the Baseline

The baseline represents a scenario without any use of biomass for energy. To show the market influence of woody biomass demand there is a need to model the baseline without energy use of woody biomass to compare the outcomes.

Figure 17 presents the baseline scenario for softwood pulpwood. Softwood pulpwood will be presented in all the scenarios since this assortment is most influenced by changes in biomass demand, assuming that 80% of bioenergy demand will utilize pine. As described before, between the years 2009 and 2015 we have a situation of recession and rebound in the market. The rate of demand change between these particular years is equal to thirty-three percent. Price changes are apparently much more dramatic than changes in removals. In 2012 prices drop by almost forty percent while removals only decrease by fifteen percent. This is due to the inelastic supply-price elasticities used in the SRTS model. Projected forest area and pine plantation area under the baseline scenario are presented in Figure 18. Declining inventory and resulting higher prices is due to the age class distribution of the inventory (Figure 19).

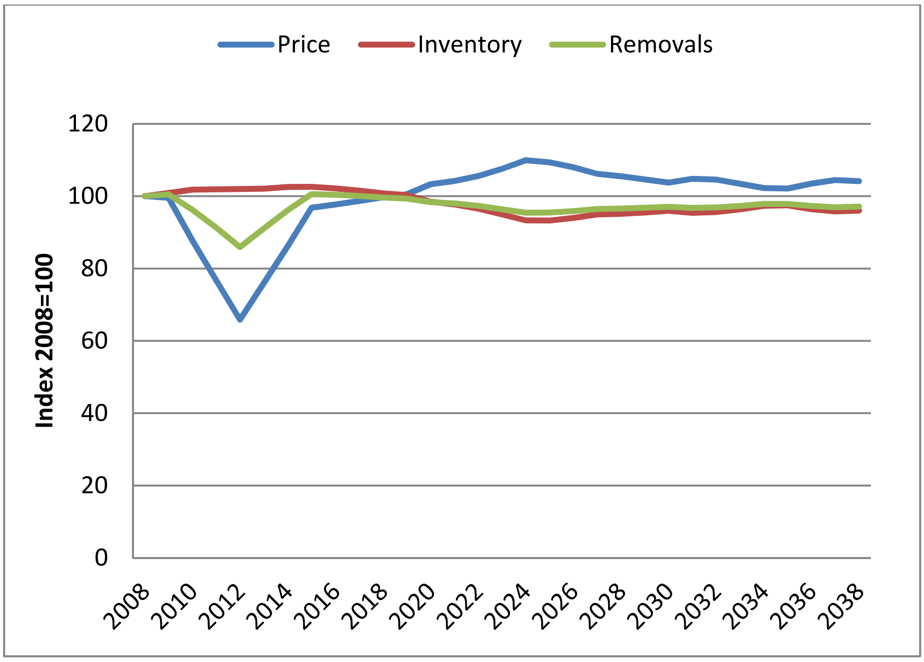


Figure 17. Baseline scenario for softwood pulpwood.

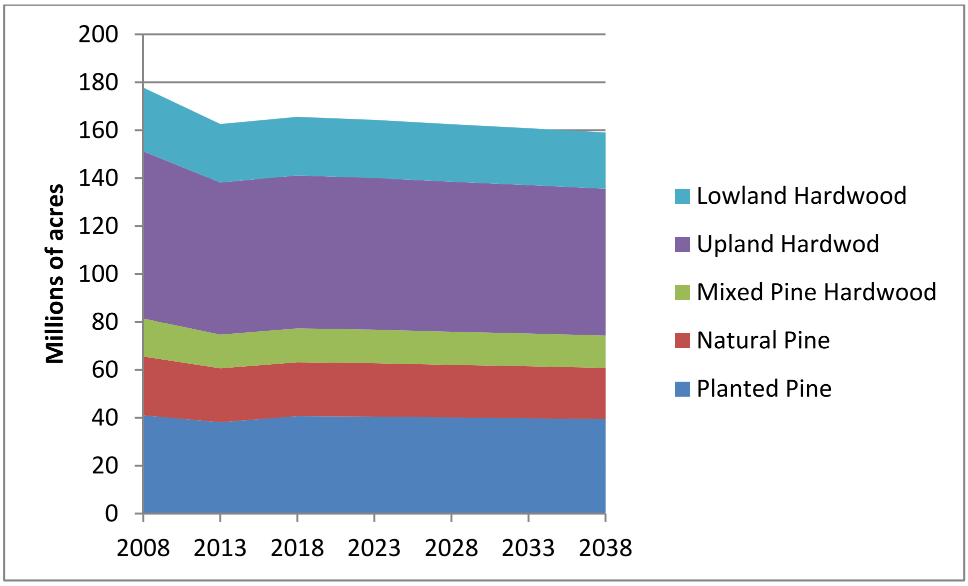


Figure 18. Projected forest area under the baseline scenario.

Pine plantations are classified into corporate and non-corporate ownership. We should bear in mind that age class distribution in Southeastern U.S. is based on real data received from FIA database from year 2009. Increasing prices after 2018, with simultaneous decreases in inventory, can be explained by two things. First of all, there is a decrease of acreage between first age class (0-4 years) and second class (5-9 years) in pine plantations. When we shift this gap over next 9-17 years, we will be able to observe the impact on the market situation. The second explanation concerns the recession and the recovery which is built into the model between 2009 and 2015. When the recession starts in 2009, prices go down, harvest drop, then there is less planting in the first five years (first age class) resulting in decrease of inventory after approximately ten years.

Figure 19. Pine plantations age class distribution in Southeastern U.S.

Sensitivity analyses

Three sensitivity analyses were done. In the first one, the medium U.S. wood fuel feedstock consumption is combined with three values (thirty, forty and fifty percent respectively) for pellets delivery to the EU. The second presents pellets moisture content in transportation and use. Results from the sensitivity analyses concern the price influence on softwood pulpwood. The third sensitivity analysis (not included in this thesis as a separate chapter) provides information regarding the rate of change of EU pellets imports (two, four and six percent respectively). The results do not indicate any significant differences between the different rates of change in the southeastern U.S. between 2020 and 2038.

The main message conveyed is that differences in price developments are insignificant for the different pellets delivery rates as well as for the different conversion factors related to the moisture content and transformation of woody biomass into pellets.

Figure 20 presents results for the sensitivity analysis regarding different percentages of pellet delivery to the EU. B1, B2 and B3 denote thirty, forty and fifty percent EU pellet delivery respectively. All scenarios follow the same trend, and they do not differ significantly. However, they all entail markedly higher prices than the baseline.

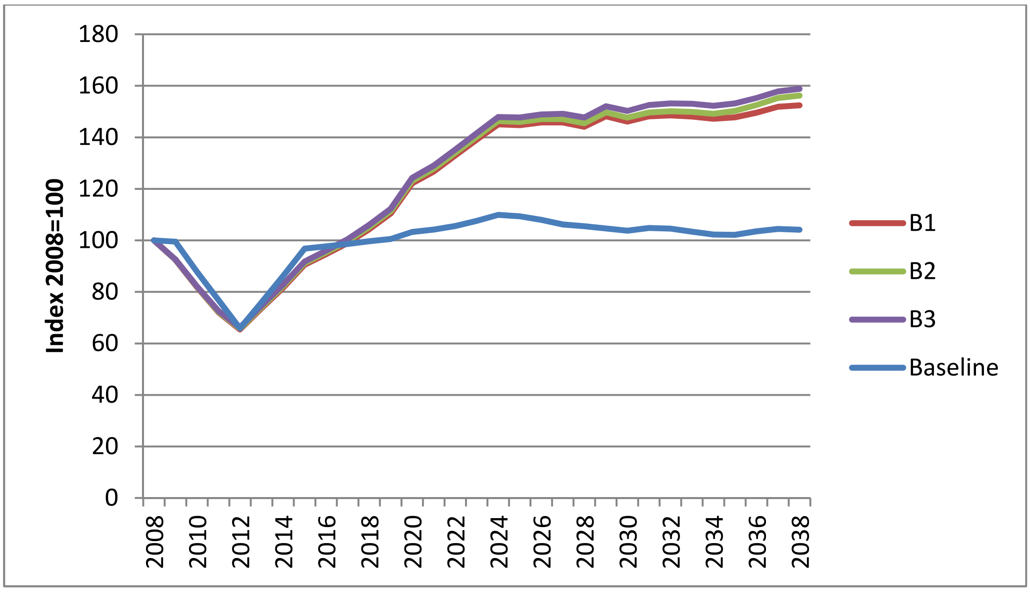


Figure 20. Softwood pulpwood biomass prices change under scenarios related to U.S. percentage of pellet delivery to EU-27.

Figure 21 presents the results of moisture content sensitivity analysis. For the analysis, the B2 scenario was used. The three scenarios, denoted B2a, B2b and B2c, were based on the conversion factors in Sikkema et al. (2010): (1.57; 1.78 and 2.12) respectively. The results indicate that the moisture content does not significantly influence the price of softwood pulpwood.

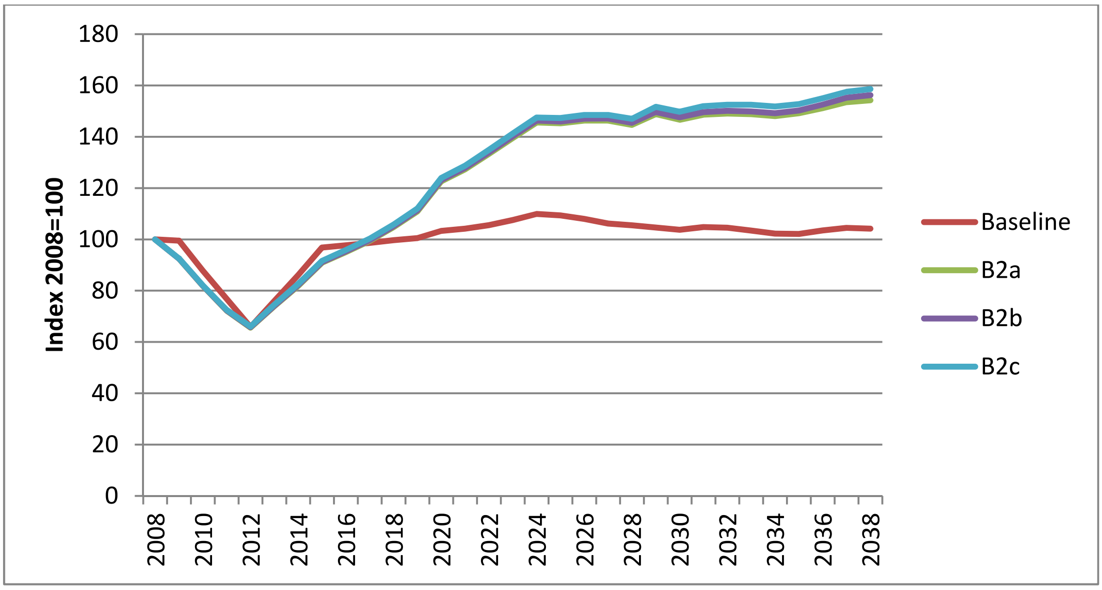


Figure 21. Softwood pulpwood biomass price change under different pellet moisture content scenarios.

Here, I present only softwood pulpwood price changes because this assortment is the one most influenced. Changes of the pellets percent delivery from U.S. to the EU-27 or change in the feedstock amount that has to be delivered to convert into pellets are definitely the factors that affect wood demand. Changes in other assortments such as softwood sawntimber, hardwood pulpwood or sawntimber were insignificant as well. Only changes in logging residues utilization show difference for B1 compared to B2 and B3.

Price, inventory and removals responses for Southeastern U.S

In this section price, inventory and removals responses under different scenarios will be presented for Southeastern U.S. Separate graphs for each of the scenarios can be found in the Appendices E-H.

Figure 22 presents changes of the inventory under different scenarios between 2008 and 2038 for softwood pulpwood. In this graph we can observe that between year 2008 and 2015, the inventory increases slightly. This situation is related to the assumptions. During recession timber harvests decrease. After 2015 we can notice a decrease in inventory caused by increasing demand for woody biomass and subsequently increases in timber harvests, especially in softwood plantations. Decreased in inventory during this period is highly correlated to increasing prices- as indicated by developments shown in Figure 23. Between 2024 and 2038 there is an apparent stabilization in inventories in the baseline as well as the A2 and B2 scenarios. The continued, albeit slower, reduction in inventory in the C2 scenario after year 2024 is a result of the larger wood consumption in this scenario.

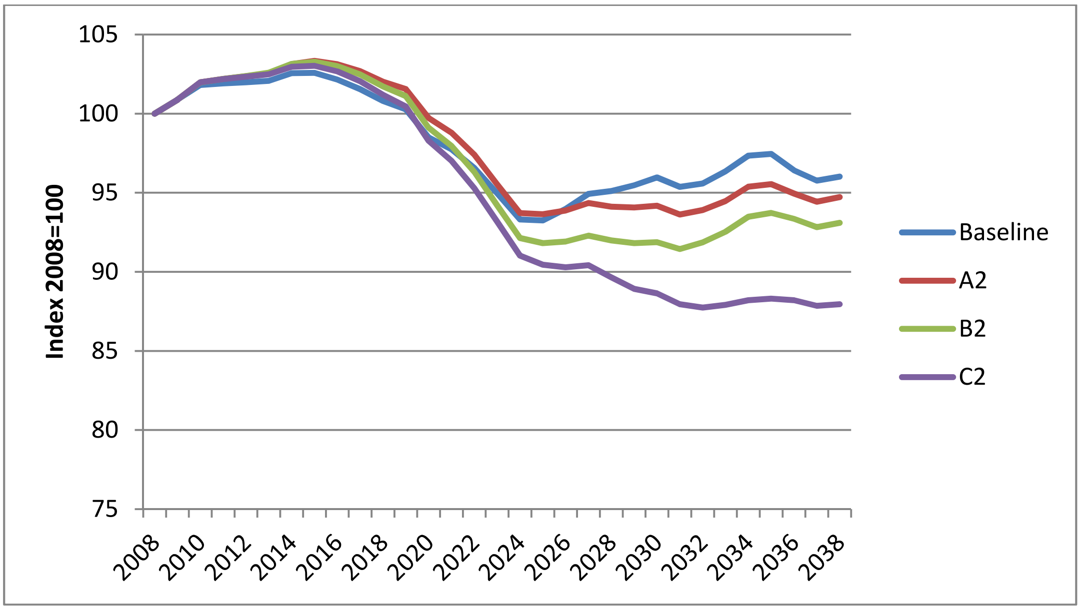


Figure 22. Change of the inventory under different scenarios between 2008 and 2038 for softwood pulpwood.

Figure 23 illustrates softwood pulpwood price developments under wood consumption scenarios. Recession and rebound is very clear in this graph. After rebound to the same level as before the recession softwood pulpwood price is starting to increase. Until 2017 price for every scenario are very close to each other. After 2024 prices in the A2 and B2 scenario are leveling out. The very elevated wood consumption in the C2 scenario drives prices to a level of around 125% higher than at the beginning of the projection. Prices in the A2 and B2 scenarios are twenty-five to fifty percent higher than in 2008. Fast price growth between 2015 and 2024 can be explained by wood scarcity related to the age class distribution. Then, increased planting and resulting higher inventories stabilizes prices. Scenario C2, with its extensive use of wood resources, apparently leads to an unsustainable use of forests in the region. The consumption is too high and production too low to fulfill existing wood gap between 2024 and 2038. Even the twenty-five to fifty percent price increases in the A2 and B2 scenarios raise questions about the resilience of wood market in the region in facing this kind of demand pressure.

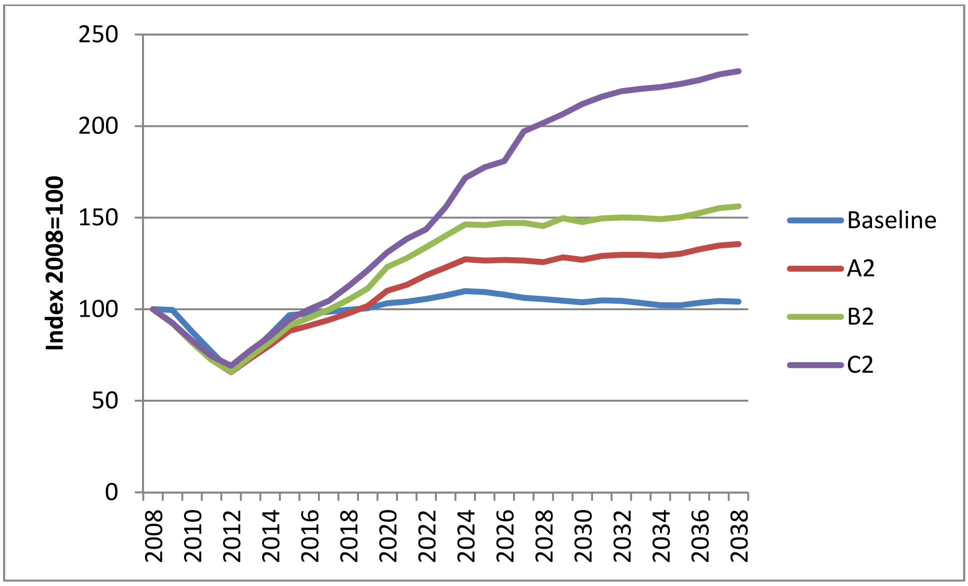


Figure 23. Change of the price under different scenarios between 2008 and 2038 for softwood pulpwood.

Figure 24 shows change in removals. There is no significant increase of the removals caused by increased wood consumption. Only for scenario C2 we can notice small bump around 2027 what probably can be caused by increases in the acreage of plantations ready to harvest. Other scenarios result in quite linear and slight increase in softwood pulpwood removals.

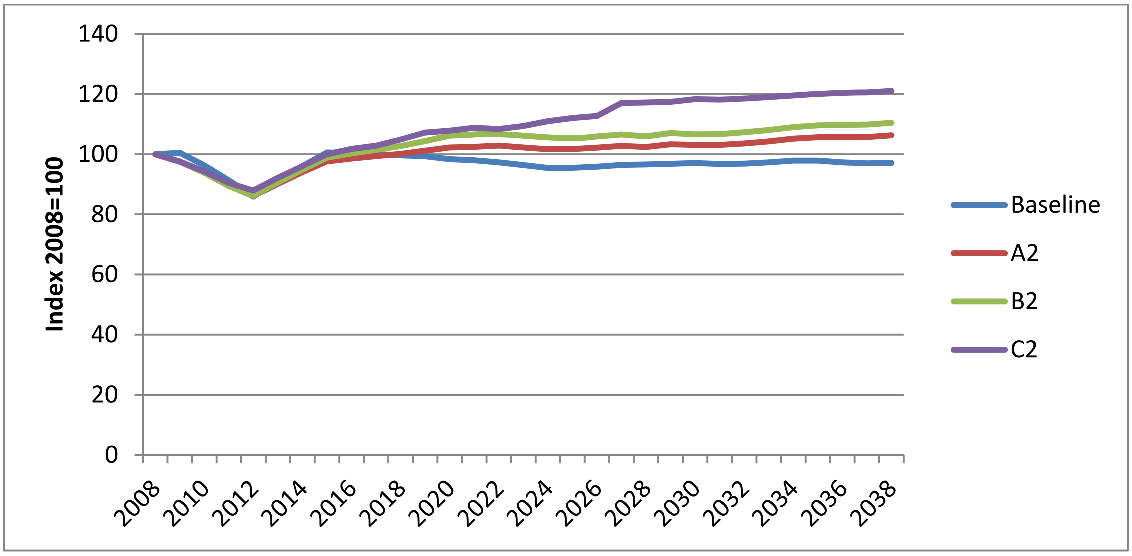


Figure 24. Change of the removals index under different scenarios between 2008 and 2038 for softwood pulpwood.

Logging residues and feedstock composition

In this section I would like to concentrate on logging residues and feedstock composition, which were significantly affected by increasing wood consumption in the modeling. Softwood residues were utilized completely during whole projection period. Figure 25 shows all scenarios that in fact overlap each other. A2, B2 and C2 scenario represent actual residual representation while maximum residual utilization is presented as shortcut MaxResidUtil. Maximum residual utilization is equal to assumed recovery rate (60%).

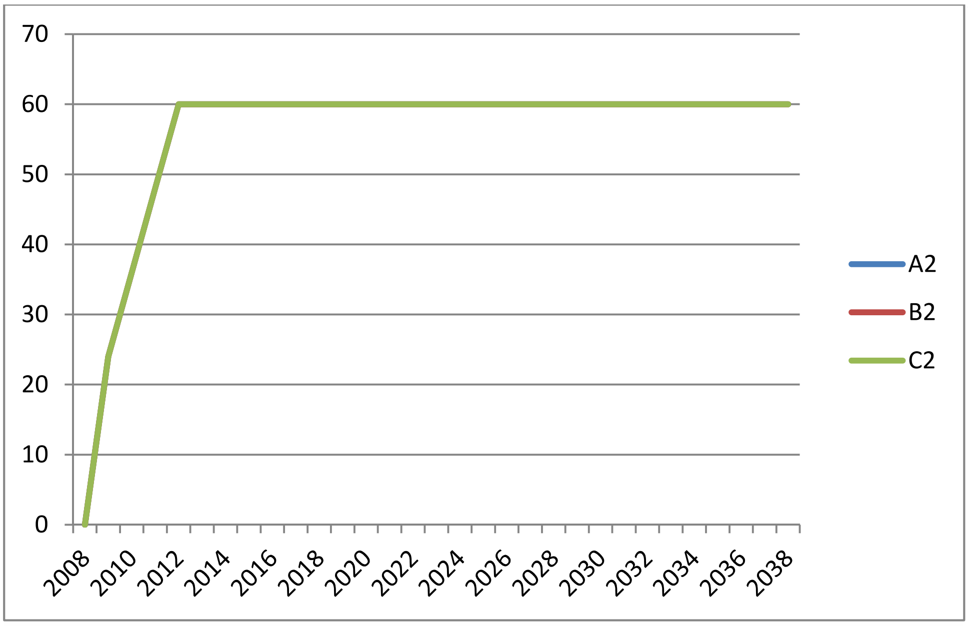


Figure 25. Logging residual utilization of softwood with 60% maximum residues utilization.

In the hardwood case situation looks differently (Figure 26). Residues are first depleted in the C2 scenario (the highest biomass consumption), followed by the B2 scenario. In the A2 scenario, hardwood residues will last until the end of the projection period. From this we can conclude that increasing woody biomass for energy consumption has a significant impact on hardwood residues utilization. Figure 25 and 26 indicate that softwood residues cannot satisfy market needs sufficiently, and thus the use of hardwood residues is required.

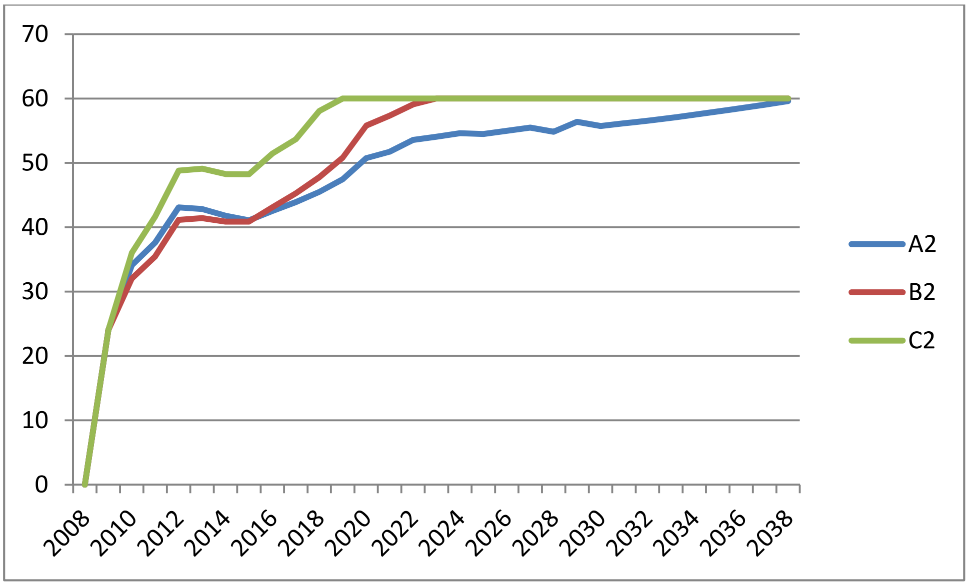


Figure 26. Logging residual utilization of hardwood with 60% maximum residues utilization.

Figure 27 shows price developments for softwood pulpwood under B scenarios. The EU pellets imports account for up to fifteen percent of the price increases.

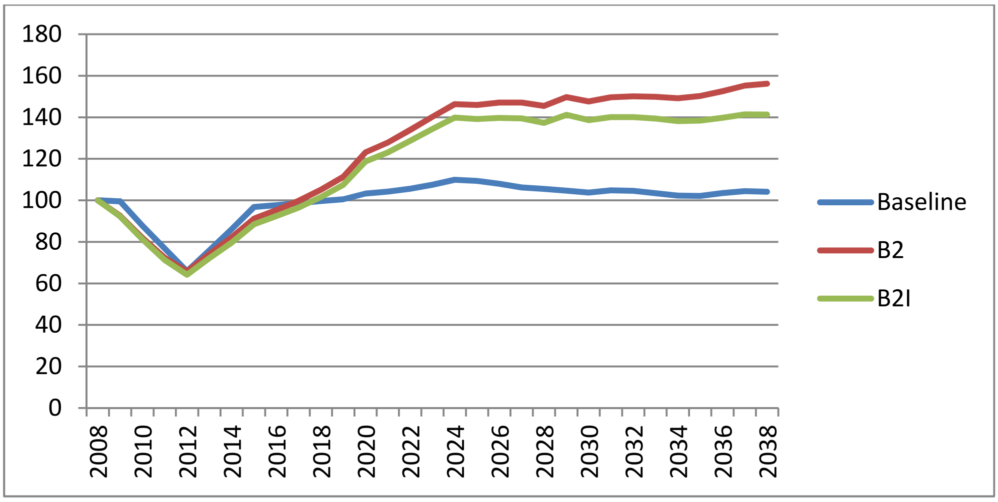
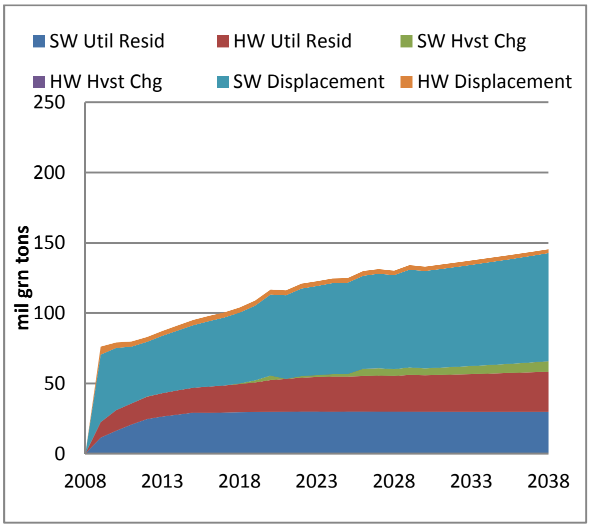


Figure 27. Price change with EU pellet consumption and without for softwood pulpwood.

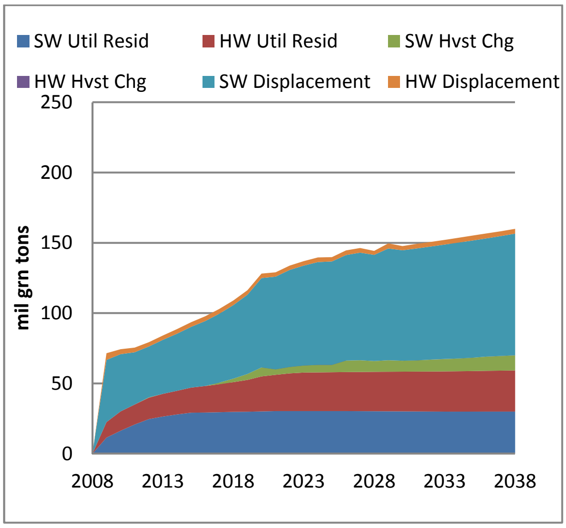
Figure 28 depicts the feedstock composition for the different scenarios. Before the description of the feedstock composition, I would like to explain the expression “bioenergy demand is inelastic", which means that bioenergy demand will be met and reductions in procurement will fall on the traditional wood users. Residues are utilized first, before any roundwood is used for bioenergy. Abt et al. (2011), explain this by the circumstance that fixed costs of logging operations encourage loggers to maximize profits at the current site, before seeking additional fiber at other sites. In this context the terms displacement refer to how the use of woody biomass for bioenergy may lead to changes in the traditional wood using industries. For example the amount of woody biomass that will be utilized for bioenergy needs rather than for pulp industry requirements. We should bear in mind that displacement included in these graphs does not take into account biomass demand response to higher prices. In reality, if prices increase, the amount of displacement should decrease.

In these projections residues are first applied to satisfy bioenergy demand. Remaining bioenergy demand is then used to shift the demand curve in the pulpwood market. If supply was perfectly elastic (horizontal) then the increase harvest would equal the increase in demand. The supply and demand elasticities in the model, however, reflect the inelastic (relatively small harvest response to price increases) nature of these markets based on empirical estimates in the literature. This means that the resulting harvest increase is only a small proportion of the biomass demand. In Figure 28 this difference is labeled "displacement" to reflect the gap between the biomass demand quantity and the quantity of residue utilization and additional harvest. The allocation of displacement between traditional forest product industries and bioenergy producers will depend on their relative demand-price elasticities.

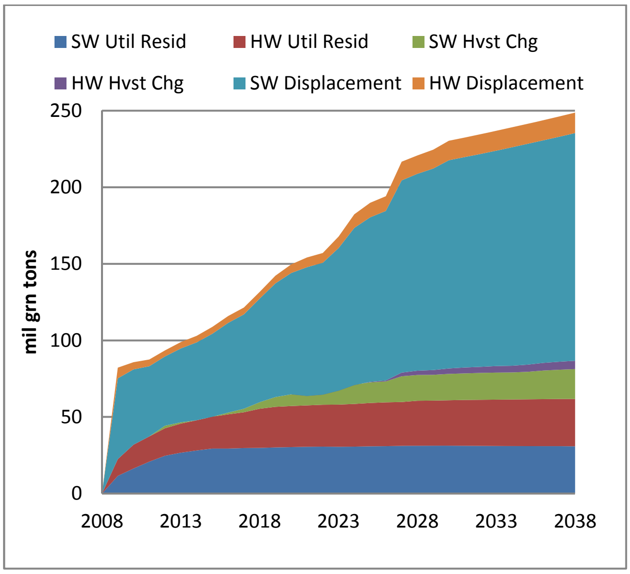
Generally scenarios A2 and B2 are very similar to each other and they seem to follow the same trend (Figure 28). Scenario C2 represents huge impact on both market and natural resources. We can observe that over 200 million green tons has to be displaced under C2 scenario if all biomass demand is going to be met. Though it is unlikely that all biomass demand will be met at higher wood prices, this scenario implies intense competition for the resources. In A2 and B2 scenarios we cannot observe hardwood harvest change while in the C2 scenario this change is visible. The increase in hardwood harvest after 2019 can be explained by depletion of hardwood logging residuals.



a) A2 scenario



b) B2 scenario



c) C2 scenario

Figure 28. Feedstock composition for Southeastern U.S. under a) A2, b) B2 and c) C2 scenarios. Abbreviations stand for: Softwood (SW) Utilization Residues, Hardwood (HW) Utilization Residues, Softwood Harvest Change, Hardwood Harvest Change, Softwood and Hardwood Displacement

Carbon storage and planting response

Carbon sequestration and storage include: sum of carbon gathered in forest floor, dead organic matter, understory, dead standing trees and live trees. Figure 29 shows the sum of all these components for the different scenarios to simplify interpretation. Data extracted from the model represent seven particular years with five year interval. The carbon storage change is not so dramatic and ranges from zero to three percent between 2008 and 2038, as compared to the baseline. Recall that Figure 29 shows carbon storage for total inventory while Figure 22 is illustrating only softwood pulpwood inventory. Generally, carbon storage increases in Southeastern U.S. under projected scenarios. The rise in softwood pulpwood prices slows the loss of timberland enough (assuming agriculture prices don't change) to offset the minor loss of pine plantation carbon.

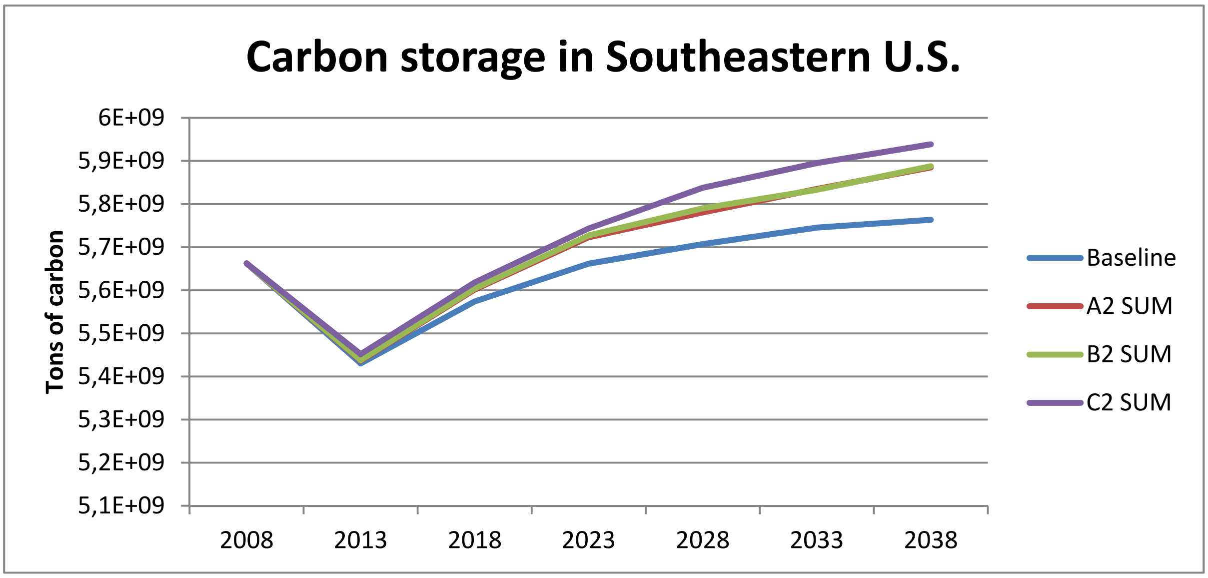


Figure 29. Carbon storage in Southeastern U.S.

Plantation acreage response on different demand scenarios is shown in the Figure 30. The same as for the carbon storage graph the scale of this graph was adjusted to show relative change. In fact the increase of softwood plantations vary between 0.4% and fourteen percent, compared to baseline. Natural pine forests, mixed pine plantations, upland hardwood and lowland hardwood do not show significant difference in planting response caused by increasing wood consumption. Plantation acreage increases as long with carbon storage, which is related to the price incentive in planting new fast growing stands. We can observe that under all scenarios the plantation area is higher than in the baseline. Only the C2 scenario shows an increasing plantation trend, which can be explained by the circumstances that only this scenario leads to a planting response strong enough to offset the loss of timber land to urban areas. Scenarios A2 and B2 follow the trend of the baseline, in that forest land is lost for urban development, roads, and other infrastructure development. To sum up, for every scenario there is a positive planting response and slower decrease in the loss of forest to urban uses.

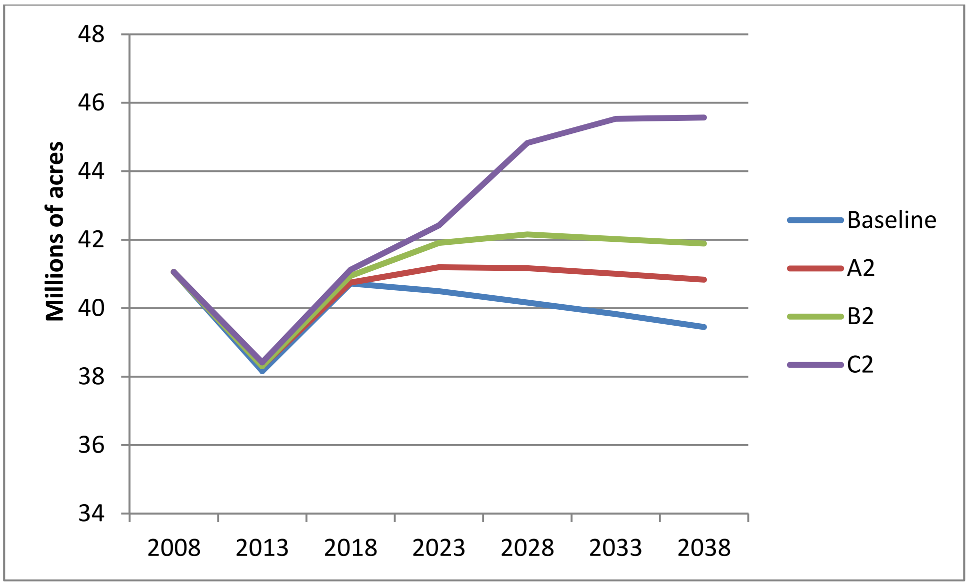


Figure 30. Plantation acreage response on consumption scenarios.

Southeastern United States coastal plain

Importance of coastal plain

Additional scenarios were developed assuming that EU pellet demand will be concentrated in the coastal plain due to concentration of pine plantations and access to ports. Based on the results from the projections for the whole region, thirty-five percent of total harvest derived from Ince et al. (2011) domestic biomass demand for the Southeastern U.S was allocated in the coastal plain. In these runs all of EU demand was assumed to come from this region.

Baseline description

The baseline projection of softwood pulpwood markets for the coastal plain of Southeastern U.S. looks very similar as the baseline for the whole SE region (Figure 31). The assumptions are exactly the same as for whole Southeastern U.S (see baseline description for SE U.S.) There is only slight change in price, inventory and removals values. In both baselines we can observe drop in inventory in year 2023. Baseline for inventory in the Southeastern U.S. shows that after the drop inventory slightly recovers while for the coastal plain inventory stays relatively flat.

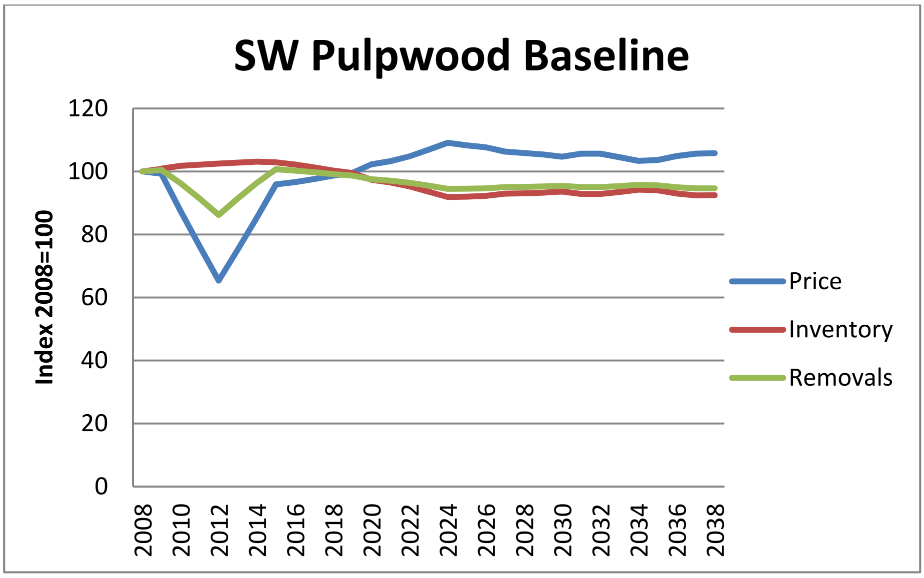


Figure 31. Baseline of softwood pulpwood for coastal plain.

Figure 32 presents projected forest area and pine plantation area under the baseline for the coastal plain.

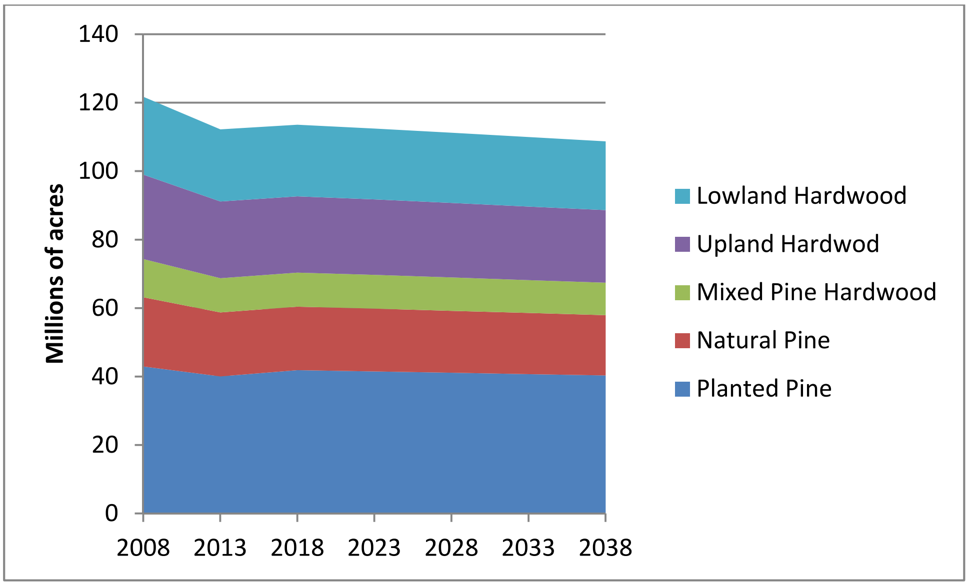


Figure 32. Projected forest area and pine plantation area for coastal plain.

The increase in price with decreasing inventory between 2018 and 2024 can be explained by the age class distribution for this particular region (Figure 33) and recession assumptions (look baseline description for whole SE U.S.). We can observe a decrease in pine plantations acreage between class 1 (1-4) and 3 (10-14). Class number 4 (11-14) is characterized by the highest value in pine plantations acres. Similarly as for the whole Southeastern U.S. region, there is big decrease in plantations acres after the 25 year age class, reflecting the relative short rotation period for pine plantations.

Figure 33. Pine plantations age class distribution in Southeastern U.S. coastal plain

Figure 34 shows age class distributions for the whole SE U.S. and for the coastal States' only (Figure 34). Most noteworthy, is the circumstance that while for the whole Southeast the acreage of softwood plantations are lower for the age class of 21-24 years, for the coastal region the acreage of this age class is at the same level as for the lower age classes.

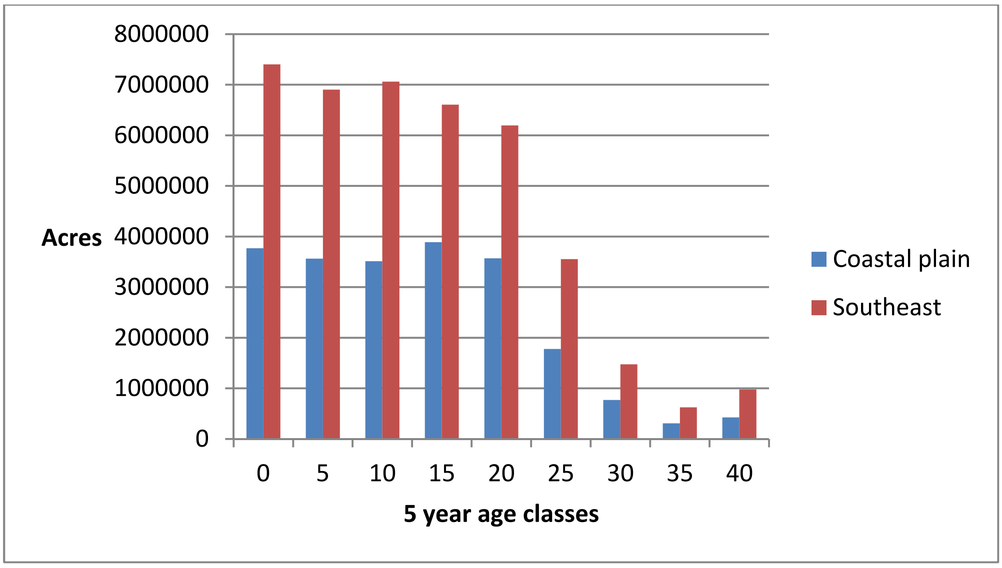


Figure 34. Combined age class distribution for corporate and non-corporate owners.

Price, inventory and removals responses for Southeastern U.S coastal plain

Description of the results for Southeastern U.S. coast will be based on the same order as for the whole SE U.S. For easier analysis and interpretation graphs will show all scenarios together. Individual graphs for each scenario can be found in Appendices I-L. In this section only softwood pulpwood will be described as the influence on other products was insignificant. Details can be found in the Appendix I.

Below we can see the projected development of the inventory under different scenarios between 2008 and 2038 for softwood pulpwood (Figure 35). There are significant differences between the different scenarios. Inventory decreases from ten to almost twenty percent due to increased wood consumption in this region. Comparison of the whole Southeastern U.S. and its coastal area indicates that the decrease in inventory is higher in the coastal area. In the Southeastern U.S., decreases in the inventory compared to the baseline at the end of the projection are one, three and eight percent for the A2, B2 and C2 scenarios respectively, while for the coastal plain the inventory decreased by three, five and eleven percent for the A2E, B2E and C2E scenarios respectively.

For the coastal area, the inventory decreases with small fluctuations for the A2E and B2E scenarios between 2024 and 2038 while for the whole Southeastern U.S., inventory slightly increases during this period. On the other hand, in C2E scenario, the inventory decreases quite dramatically, while for whole SE U.S. it stabilizes. The coastal plain represents a smaller area so the impact of woody biomass consumption is higher than for the whole Southeastern region. Recall figure 16, how dramatically pellets contribution in total biomass consumption increases during last years of the projection for the coastal plain, due to an assumption of six percent annual increases.

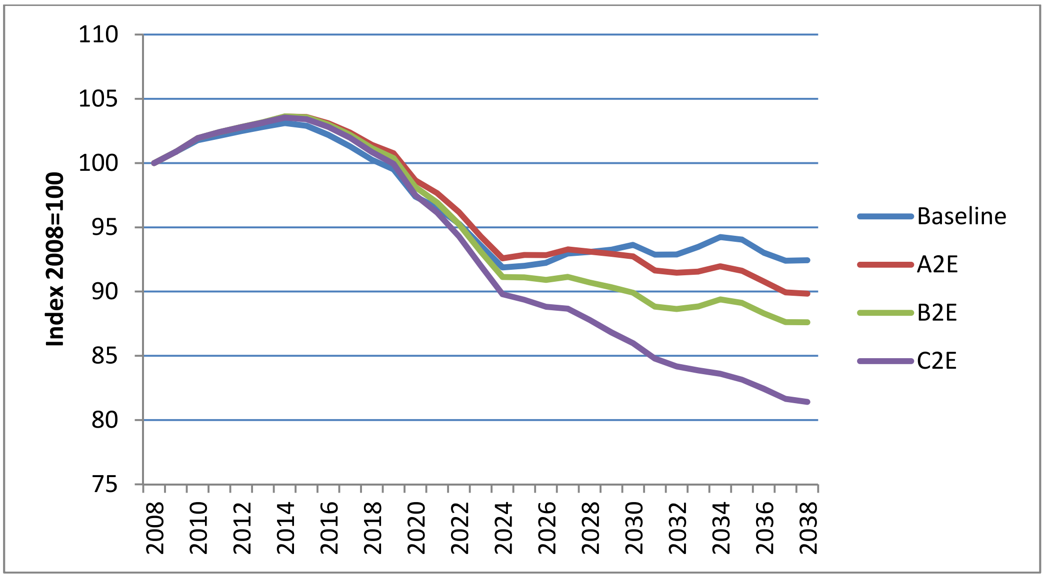


Figure 35. Change of the inventory under different scenarios between 2008 and 2038 for softwood pulpwood on the coastal plain.

Next we turn our attention to the price developments for the coastal region (Figure 36). Prices increase, and the growth in the coastal plain is more linear than for Southeastern U.S. region. It can be explained by the age class distribution, which for the coastal plain is less favorable (see figure 33 and 34). The impact on prices is higher than for the whole Southeastern U.S. In the Southeastern U.S. price increases equal thirty-one, fifty-two percent and 126% for the low, medium and high scenarios respectively. On the coastal plain, price increases for whole projection period are forty-two percent, 61% and 127% for the A2E, B2E and C2E scenarios respectively. Price increases are given as compared to the baseline at the end of the projection (2038). I would like to point out that the C2E scenario has a huge impact not only on the price of softwood pulpwood, but also on hardwood pulpwood in the coastal plain (see Appendix Kd).

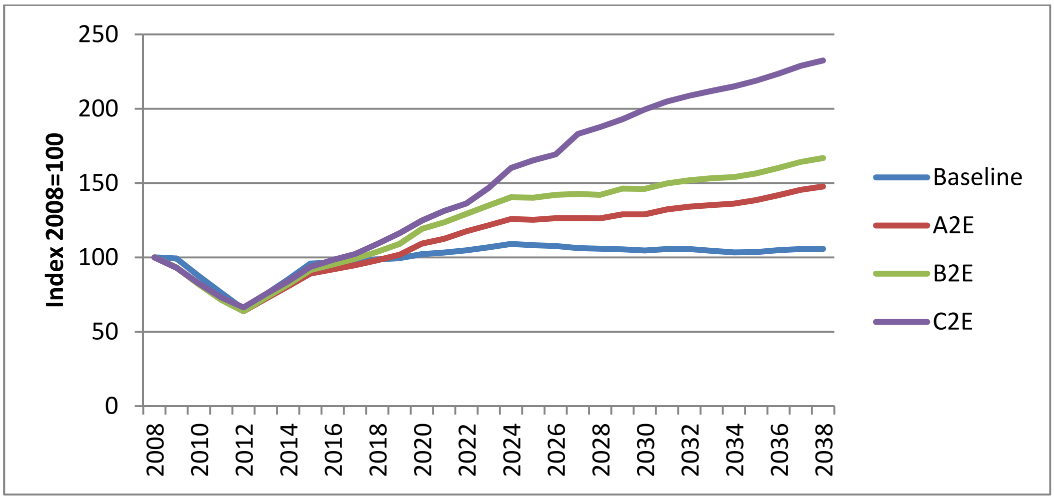


Figure 36. Change of the price under different scenarios between 2008 and 2038 for softwood pulpwood.

Figure 37 shows developments in removals between 2008 and 2038 for the coastal States'. Removal in the A2E and B2E scenarios are higher than in the baseline. The C2E scenario shows increasing removals, around eighteen percent higher than at the beginning of the projection. The C2E scenario presents a higher impact on both forest resources and wood market, in order to mobilize extra harvest to fulfill the wood consumption requirements. Changes in removals are highly correlated to the age class distribution (Figures 33, 34) and inventory (Figure 35), that creates a 'gap' in wood production and there is not much increase in harvest for the same demand. The difference between baseline and particular scenarios at the end of the projection is equal to eleven, thirteen and nineteen percent for the A2E, B2E and C2E scenarios respectively. For the whole Southeastern U.S., the corresponding figures are nine, thirteen and twenty-four percent respectively.

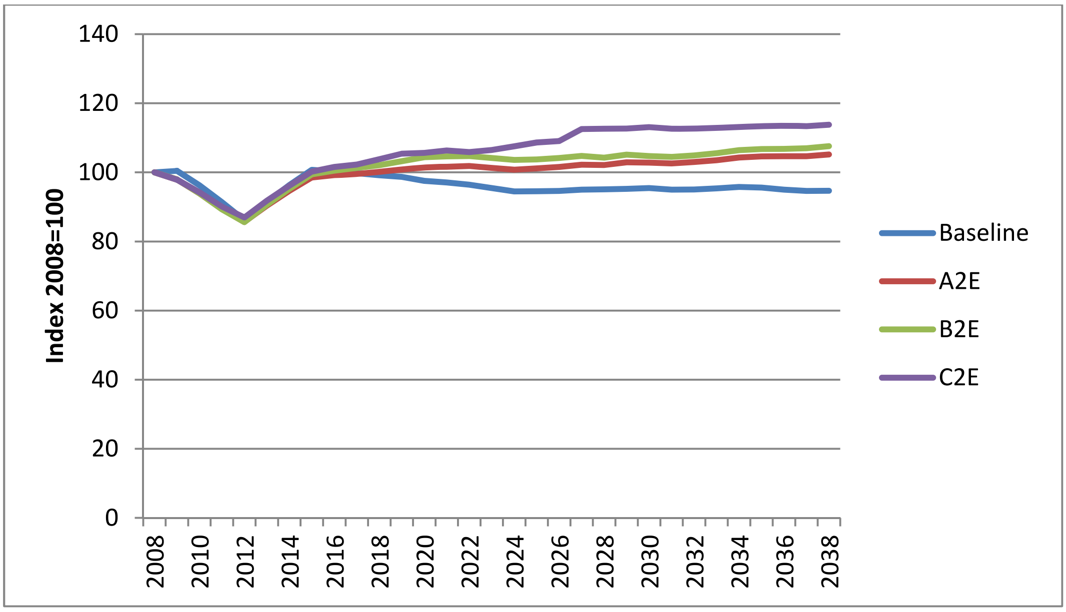


Figure 37. Change of the removals under different scenarios between 2008 and 2038 for softwood pulpwood.

Logging residues and feedstock composition

Similarly to Southeastern U.S., softwood residues were utilized completely from the beginning of the projection on the coast. Figure 38 shows that residues utilization follows the maximum residues utilization rate from 2008 to 2038. It means that all available residues were used to address biomass demand.

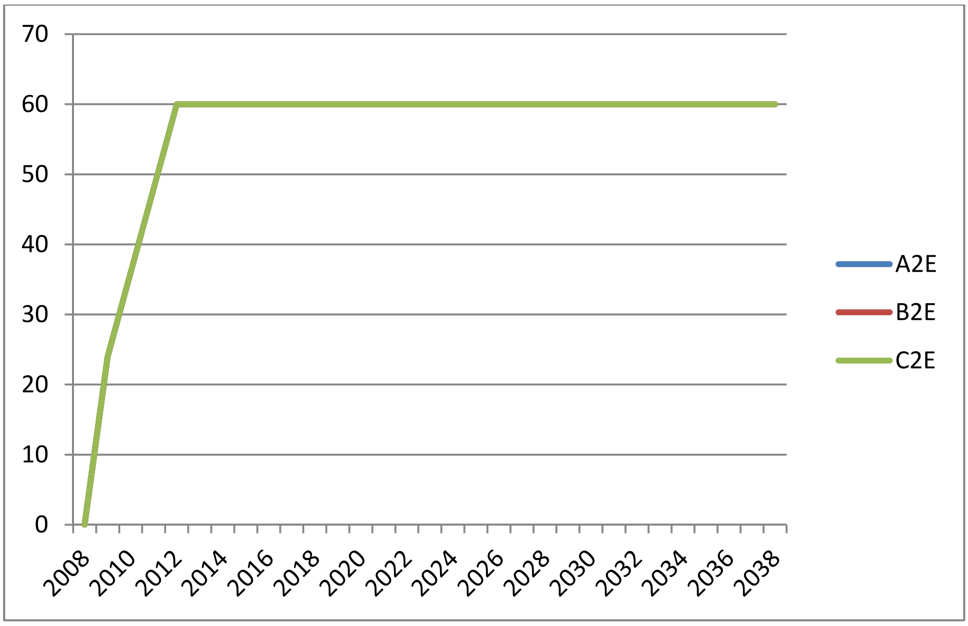


Figure 38. Logging residual utilization of softwood with 60% maximum residues utilization.

Figure 39 depicts logging residual utilization for hardwood. Generally, hardwood residues follow the maximum residual utilization from the beginning of the projection. There are, for B2E scenario only just minor differences between 2012 and 2015. For the A2E and C2E scenarios, the situation looks similar to softwood residues, where logging residual utilization of hardwood follows exactly assumed maximum utilization rate throughout the projection period.

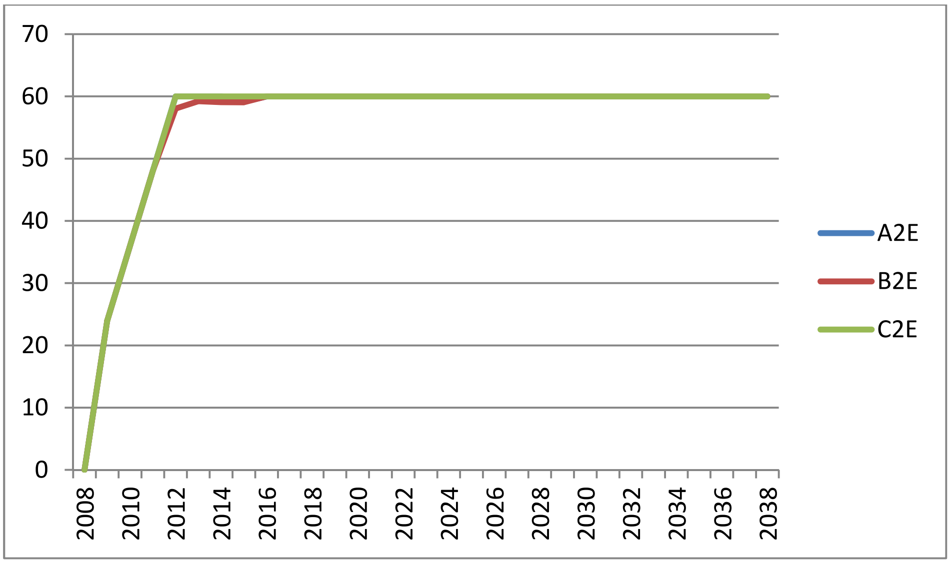


Figure 39. Logging residual utilization of hardwood with 60% maximum residues utilization.

Figure 40 presents the impact on the prices of EU for softwood pulpwood between 2008 and 2038 for the B scenarios. Looking at this graph we can notice in the first glance that EU contribution to the prices for this assortment is much higher than we saw for whole Southeastern U.S. It is mainly caused by the assumption that whole EU biomass import will come from coastal States' instead of whole Southeastern U.S. For all scenarios, the range of EU price contribution is from almost zero at the beginning of the projection up to thirty-two percent at the end.

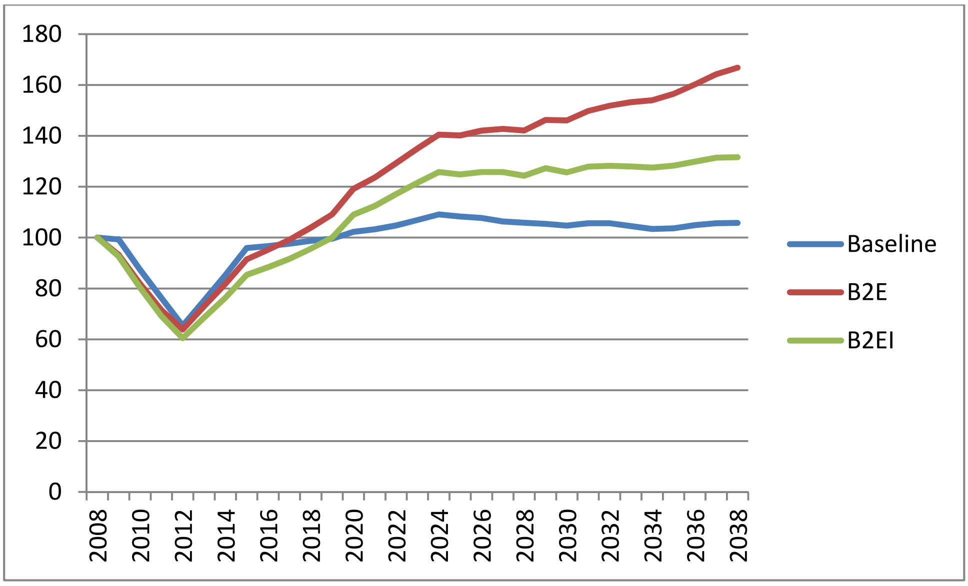
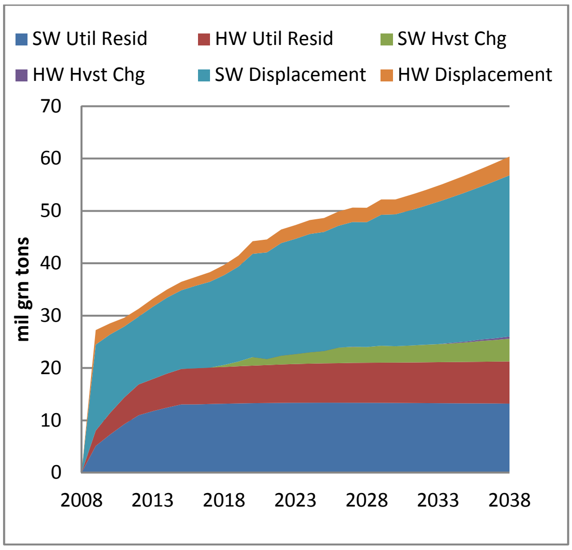
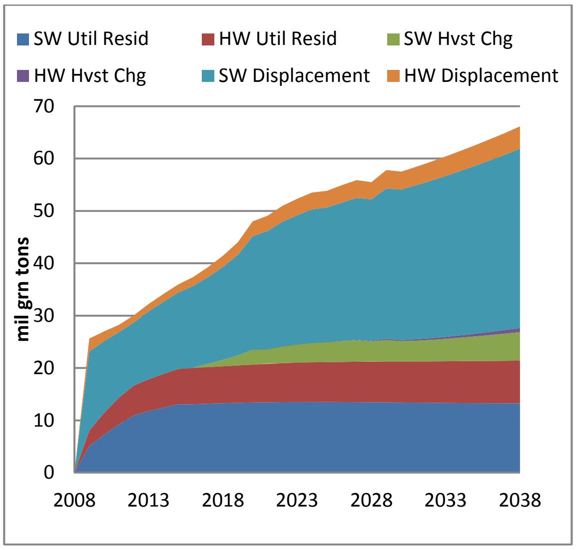


Figure 40. Price changes with EU pellets imports and without for softwood pulpwood.

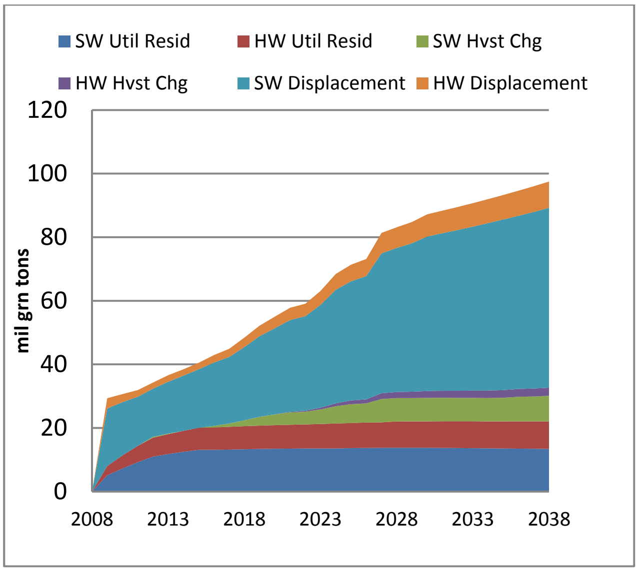
Intensive and rapid utilization of available residues imply that other wood assortments, such as pulpwood, will be affected, i.e., one can expect displacement of traditional wood-using industries.



a) A2E scenario



b) B2E scenario



c) C2E scenario

Figure 41. Feedstock composition for the coastal plain under a) A2E, b) B2E and c) C2E scenarios. Shortcuts stand for: Softwood (SW) Utilization Residues, Hardwood (HW) Utilization Residues, Softwood Harvest Change, Hardwood Harvest Change, Softwood and Hardwood Displacement.

Figure 41 presents feedstock composition, and indicates softwood and hardwood displacement. I would like to emphasize one more time that displacement included in these graphs do not take into account biomass demand response to higher prices. In other words, there is an assumption that biomass demand will be met regardless the price. Looking at three scenarios for the coastal States, we can observe a change in softwood displacement. At the end the projection (in year 2038), it varies from 60 (the A2E scenario) up to 100 million green tons (the C2E scenario). This dramatic change, would it take place, could significantly change the wood industry structure on the coast of Southeastern U.S. Most affected would be the pulp wood industry. Timber, instead of being used for pulp and paper production, would be utilized for bioenergy purposes. We can also notice a slower but nevertheless important increase in hardwood displacement. The total feedstock composition in the Coastal area is roughly 2.5 times smaller than for the whole Southeastern U.S. Softwood and hardwood displacement of this magnitude could lead to an unsustainable use of forest resources, jeopardizing employment in the wood-products industry in the region in the longer term.

Carbon storage and planting response

Figure 42 illustrates carbon storage on the coast of Southeastern U.S. looking at the graph, one should bear in mind that percentage change between all scenarios and the baseline is less than one percent. Generally, projected carbon storage increases until 2028. Again we should bear in mind that, carbon storage figure presents data for total inventory, while Figure 35 was showing a decrease of inventory for softwood pulpwood only. The increase in carbon storage is caused by price incentives and ensuing increased establishment of pine plantations by forest owners. After the year 2028, carbon storage decreases slightly, which can be explained by increased harvesting. The most dramatic change takes place in the C2E scenario, where rapid increased harvest entails losses of forest carbon.

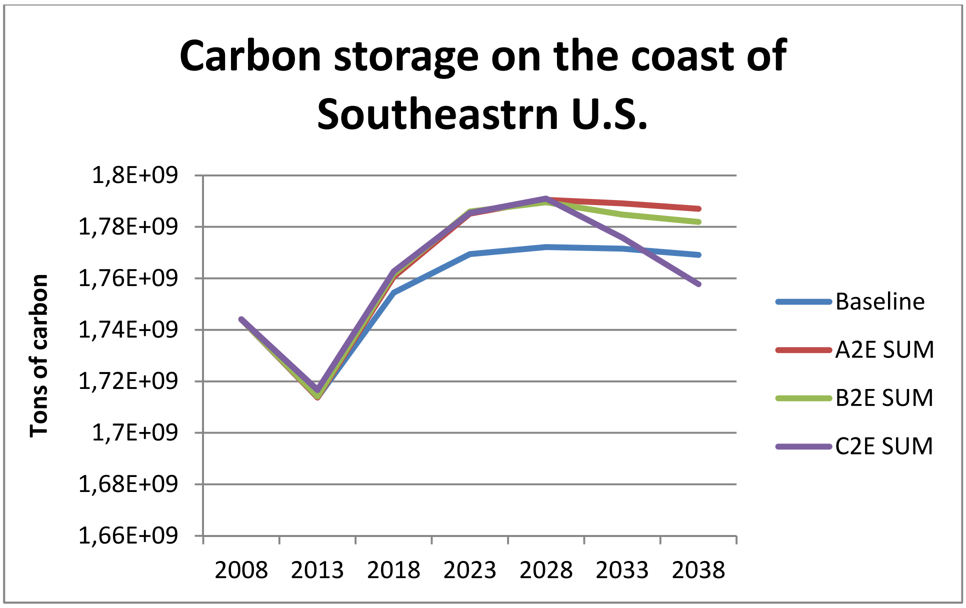


Figure 42. Carbon storage in the coastal plain in the Southeastern U.S.

Plantation response is presented in Figure 43. This graph shows that carbon losses are partially offset by a planting response. We can notice that under all scenarios plantation acreage is higher than in the baseline. The A2E and B2E scenarios exhibit a stabilizing trend. Only the C2E scenario, in exactly the same way as the C2 scenario for the whole Southeastern U.S, can lead to higher planting response strong enough to offset the loss of timber land. To summarize, every scenario can be characterized by positive planting response and gains in forestland relative to agriculture land.

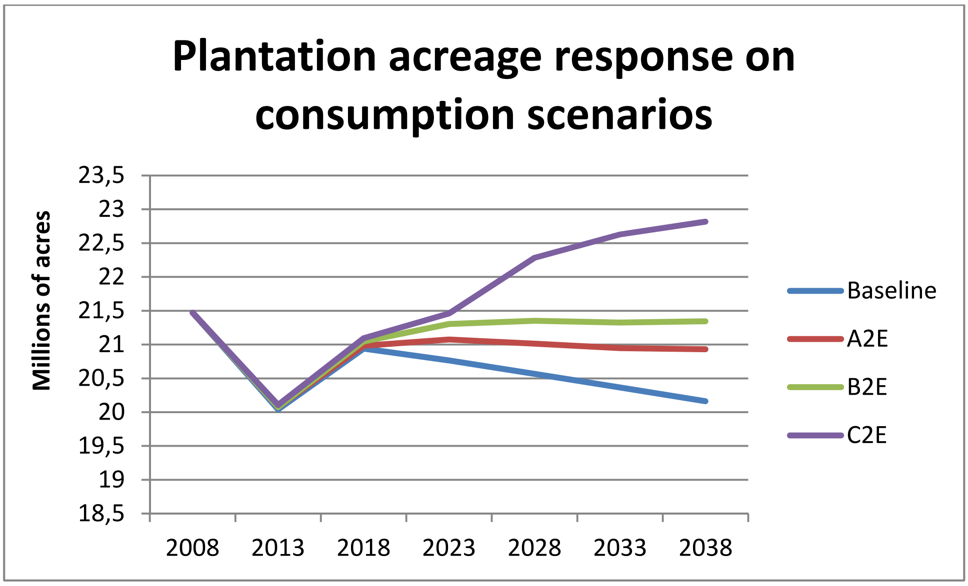


Figure 43. Plantation acreage response on consumption scenarios.

SUMMARY AND CONCLUSIONS

This paper assesses the influence of European Union wood biomass consumption on the forest market and carbon storage in Southeastern United States'. All the conclusions included in this section cover both the Southeastern U.S as a whole and its coastal sub-region. Because of the diversity of the topics researched, this chapter will be divided in three parts. The first part describes results related to the consequences and impacts of wood utilization on market behavior. In this section, the combined results for both examined regions developments in prices, inventories, and removals will be analyzed.

The second section concentrates on the influence of wood use on forest resources. This part emphasizes the importance of carbon storage, planting response and logging residues utilization. Finally, the third section, based on the two previous ones, analyzes the current policy as regards biomass use and its future development. In addition, this part stresses the relationship between wood markets and forest resources, and concludes that these two fields cannot be treated separately in renewable energy policy analysis. The two first sections can be described as positive economics, whereas the last one has features of normative economics related to the Author's own best estimates of reasonable scenarios, based on literature review.

Wood utilization and its influence on market behavior

First of all, I would like to start from the sensitivity analysis results that show that neither percentage (within the ranged examined here) of biomass delivery to EU nor moisture content of pellets significantly influence the wood market in the Southeastern U.S. Under all scenarios, the difference in price change was quite limited. This implies that even if the share of EU pellets consumption U.S. will increase from thirty percent up to as much as fifty percent, or if changes in pellets standards will occur, especially a decrease in moisture content, Southeastern U.S. will not experience dramatic changes in wood consumption or prices.

Under all biomass consumption scenarios, scenario C2 for SE US and C2E for coastal States' cause the biggest impact on wood market and natural resources in these regions. Compare to other scenarios only these two caused structural changes. Both A and B scenario were very similar in terms of impact on market behavior. There is a small increase in wood volume used, the impact on price is more noticeable. For both regions and under all projected scenarios, softwood roundwood price increases are in the range from around twenty-five to 125% by 2038.

U.S. domestic wood fuel feedstock utilization has the main impact on wood market in Southeastern U.S and its coastal plain. Hence, in both the EU and U.S. price contribution graphs we were able to notice that EU wood consumption and import from SE U.S. is not as significant as domestic wood usage.

Wood utilization and its influence on forest resources

A key result is related to biomass utilization and its impact on carbon storage. Under all scenarios and for both projected regions, carbon storage increases due to a positive planting response among private forest owners compared to the baseline scenario. High wood demand causes a price signal for private forest owners to plant trees. Moreover, newly established plantations compensate carbon loss from higher harvest levels. A positive planting response may be advantageous both to regional economy and the environment.

All of the market impacts discussed above assume full utilization (60%) of available residues with a minor exception for hardwood residues in A2. This level of utilization may jeopardize sustainable forest management; negatively impacting on biodiversity, and other ecosystem services. Further research is needed to address this issue.

Possible research improvement

In this section I would like to concentrate on obstacles and data gaps which knowledge in close future can improve research in renewable energy policy analysis and international biomass trade. Based on literature review, bioenergy policy seems to be the most influential factor on wood utilization and trade. More detailed determination and update of domestic U.S. and EU policy can significantly improve the state of current knowledge and can help to clarify many assumptions. Next, incorporation of price sensitivity of biomass demand in the European Union can be crucial for further research. Moreover, more specific data on wood flows from and to different countries, connected with clear specification of product codes and relatively quick actualization of databases can make an important step towards possible research improvement. Last but not least, development and link between EU demand models and U.S. supply models can solve many problems related to data deficiencies.

Biomass use and its future development

Both United States and European Union policy is important in the perspective of sustainable use of natural resources and international wood market and trade. In this study, the costs of EU imports are very sensitive to U.S. domestic renewable energy policy which is uncertain.

There is much evidence that biomass trade, especially in pellet sector, will increase. Every country in close future will have to determine the policy, biomass and certification standards of biomass trade. Too high a wood demand can cause increased pressure on natural resources. Biomass prices will influence the costs of bioenergy, which at the beginning are not enough to be competitive with fossil fuels. That is why in short run help and subsidies from the governments are needed to develop this branch of forest industry. In the longer perspective, when the infrastructure will be more developed, the trade connection will be stable and there will exist specified and transparent law about biomass and bioenergy, then this kind of renewable energy might be highly competitive with fossil fuels. A better functioning market is the matter of both time and policy reform. Increasing biomass demand will drive progressive infrastructure development while policy reforms can accelerate this process.

In my opinion policy reforms such as biomass subsidies, higher fossil fuel taxes, and investments in other renewable energy sources are highly important and needed in the short time scale. Looking for alternative energy sources now can halt consequences related to depletion of fossil fuels in the future and reduce possible impacts of climate change.

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Appendix A: Share of renewable energy in gross final energy consumption.

	%			
geo\time	2006	2007	2008	TARGET
European Union (27 countries)	8.9	9.7	10.3	20
Belgium	2.7	3	3.3	13
Bulgaria	9.3	9.1	9.4	16
Czech Republic	6.4	7.3	7.2	13
Denmark	16.8	18.1	18.8	30
Germany (including former GDR from 1991)	7	9.1	9.1	18
Estonia	16.1	17.1	19.1	25
Ireland	3	3.4	3.8	16
Greece	7.2	8.1	8	18
Spain	9.1	9.6	10.7	20
France	9.6	10.2	11	23
Italy	5.3	5.2	6.8	17
Cyprus	2.5	3.1	4.1	13
Latvia	31.3	29.7	29.9	40
Lithuania	14.7	14.2	15.3	23
Luxembourg	0.9	2	2.1	11
Hungary	5.1	6	6.6	13
Malta	0.1	0.2	0.2	10
Netherlands	2.5	3	3.2	14
Austria	24.8	26.6	28.5	34
Poland	7.4	7.4	7.9	15
Portugal	20.5	22.2	23.2	31
Romania	17.5	18.7	20.4	24
Slovenia	15.5	15.6	15.1	25
Slovakia	6.2	7.4	8.4	14
Finland	29.2	28.9	30.5	38
Sweden	42.7	44.2	44.4	49
United Kingdom	1.5	1.7	2.2	15

:=Not available

Source: Eurostat

Appendix B. Projection of pellet production and consumption between 2009 and 2020 in the European Union.

year	Yearly increase rate %	Production	Yearly increase rate %	Consumption
2006	0.28	4.615.340	0.23	4.749.000
2007	0.25	5.942.827	0.37	5.866.800
2008	0.20	7.429.440	0.25	8.060.650
2009	0,20	8.915.328	0,25	10.075.813
2010	0,15	10.252.627	0,2	12.090.975
2011	0,10	11.277.890	0,15	13.904.621
2012	0,09	12.292.900	0,13	15.712.222
2013	0,08	13.276.332	0,12	17.597.689
2014	0,03	13.674.622	0,07	18.829.527
2015	0,05	14.358.353	0,05	19.771.003
2016	0,05	15.076.271	0,05	20.759.553
2017	0,06	15.980.847	0,06	22.005.127
2018	0,06	16.939.698	0,06	23.325.434
2019	0,06	17.956.080	0,06	24.724.960
2020	0,06	19.033.444	0,06	26.208.458

Source: Capciolli S., Vivarelli F. (2009).

Appendix C. Renewable energy projections and other key economic assumptions.

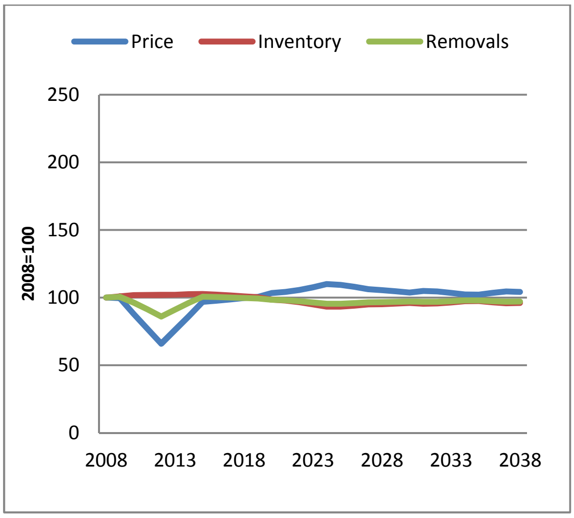
Scenario	RFS + RES10	RFS + RES20 + EFF	RFS + RES20	RFS + RES20 + HP
Basis for U.S. wood energy projections	AEO Reference Case RFS, and RES10	AEO Reference Case RFS, and RES20 + EFF	AEO Reference Case RFS, and RES20	AEO High Oil Price Case RFS, and hypo-thetical RES20
Wood % of U.S. primary energy consumption in 2030	1.30%	1.60%	1.80%	2.50%
U.S. housing starts	AEO Reference Case			
U.S. GDP growth	AEO Reference Case			AEO High Oil Price Case
Global GDP growth	IMF (2006–2014), IPCC B2 Message (2015–2030)			
Fuelwood consumption in countries other than U.S.	Fuelwood consumption as a percentage of primary energy consumption remains constant (2006–2030) while energy consumption increases based on IEA projections, resulting in 65% increase in fuelwood consumption volume in total for all other countries			

Source: Ince et al. (2011)

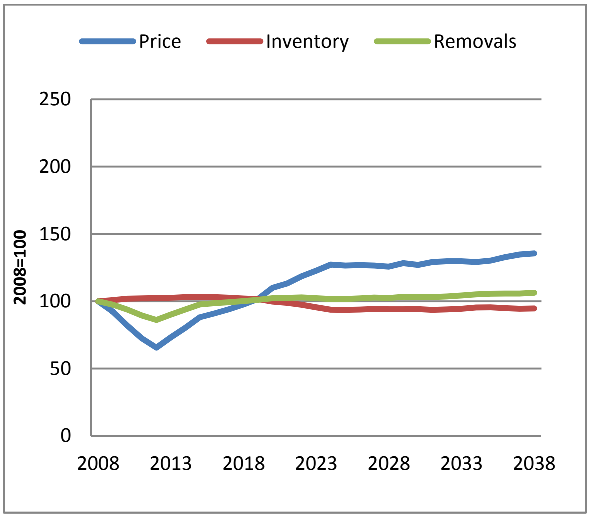
Appendix D. Wood consumption (%) of the States' located on the coast in the total wood consumption for whole Southeastern United States region between 2008-2038

Year	A2E	B2E	C2E
2008	35.09535	35.0953545	34.9150521
2009	35.11592	35.1169816	34.9144835
2010	35.18717	35.1747238	34.9910636
2011	35.35316	35.3340198	35.1750617
2012	35.56702	35.5330446	35.3919368
2013	35.71126	35.6774783	35.5189698
2014	35.73114	35.7049332	35.5211371
2015	35.7479	35.7289213	35.5270091
2016	35.78956	35.7780814	35.5728334
2017	35.83251	35.8255911	35.6033832
2018	35.87096	35.8689914	35.6506797
2019	35.91229	35.91769	35.6934156
2020	35.92163	35.9391472	35.6559589
2021	35.91277	35.9303973	35.6289721
2022	35.90069	35.9073217	35.5825293
2023	35.86527	35.8697383	35.5415769
2024	35.82714	35.8240032	35.4995951
2025	35.8391	35.8345128	35.5032354
2026	35.80764	35.7990858	35.4399639
2027	35.73852	35.7316158	35.3686969
2028	35.67466	35.66722	35.2792381
2029	35.61442	35.6109459	35.1626584
2030	35.51747	35.5065779	35.0358648
2031	35.49304	35.4610345	34.9525512
2032	35.44297	35.4279026	34.8756784
2033	35.40922	35.3899384	34.7978098
2034	35.38609	35.3724111	34.7219297
2035	35.37511	35.3536806	34.6694141
2036	35.36428	35.3470155	34.6145223
2037	35.34798	35.3243749	34.564132
2038	35.31689	35.3036981	34.5211915

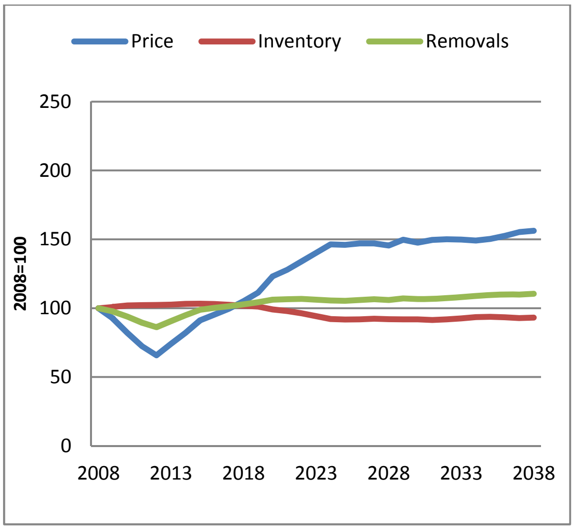
Appendix E. Softwood pulpwood- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for Southeastern U.S. between 2008 and 2038



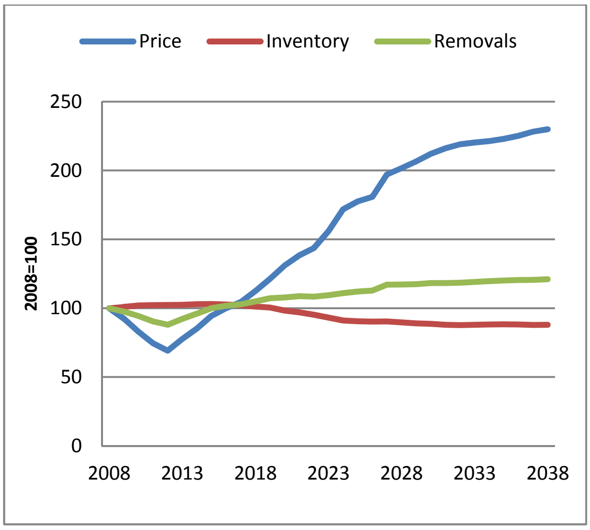
a) Baseline: traditional demand with no bioenergy



b) A2 scenario

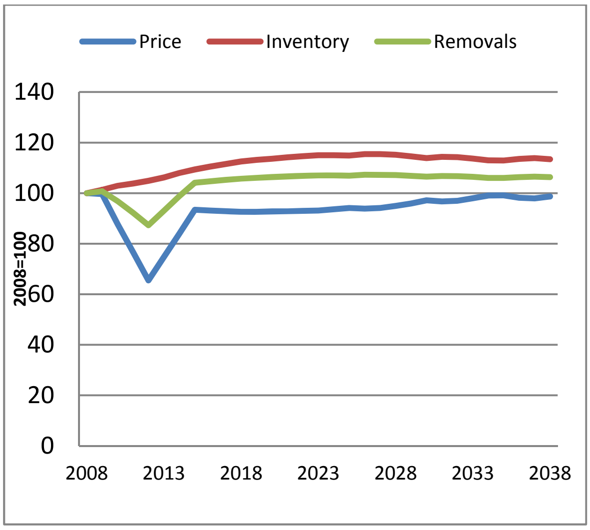


c) B2 scenario

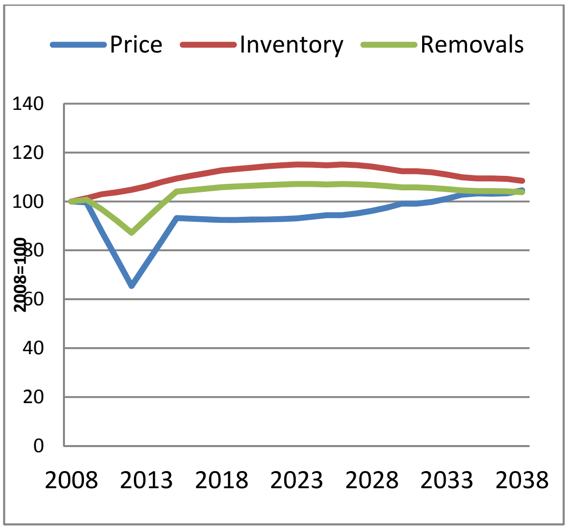


d) C2 scenario

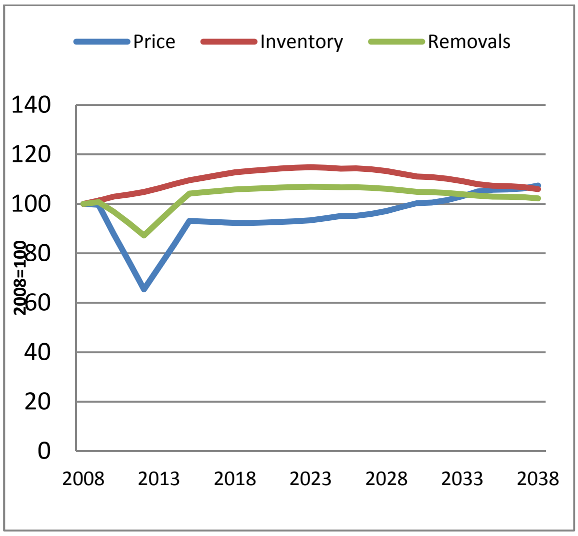
Appendix F. Softwood sawtimber- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for Southeastern U.S. between 2008 and 2038



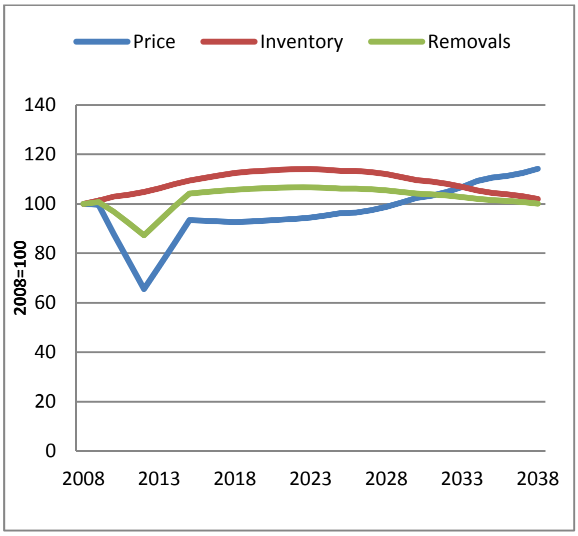
a) Baseline: traditional demand with no bioenergy



b) A2 scenario

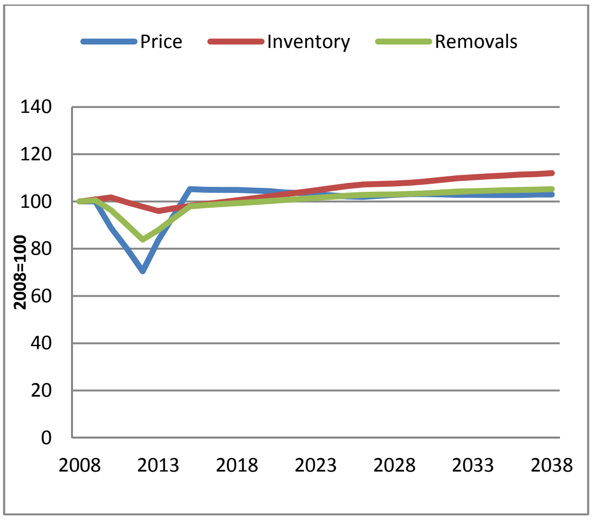


c) B2 scenario

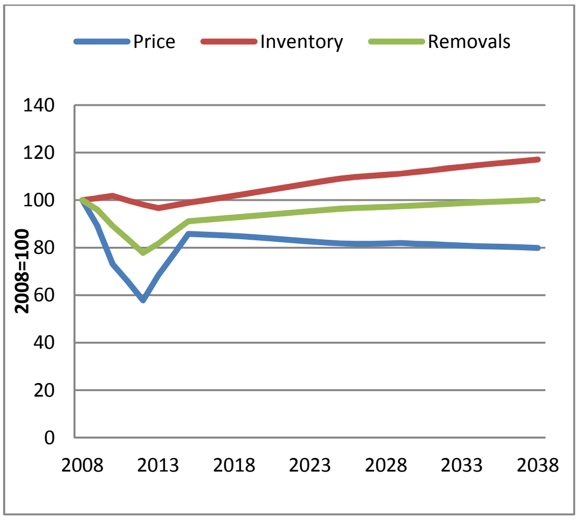


d) C2 scenario

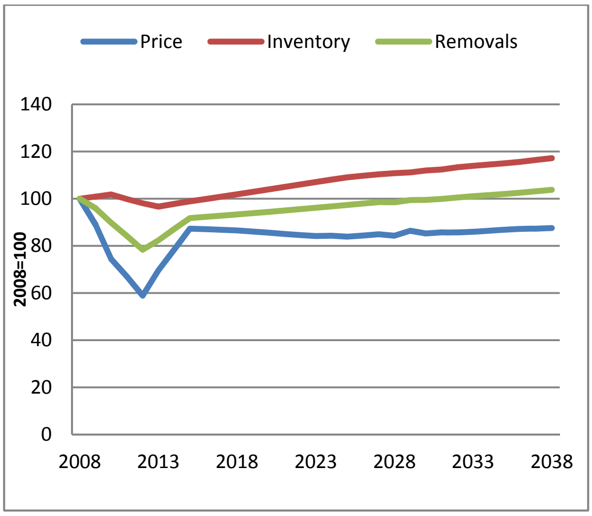
Appendix G. Hardwood pulpwood- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for Southeastern U.S. between 2008 and 2038



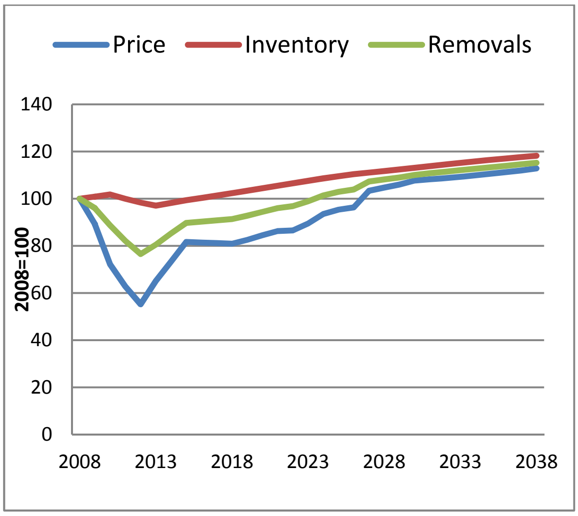
a) Baseline: traditional demand with no bioenergy



b) A2 scenario

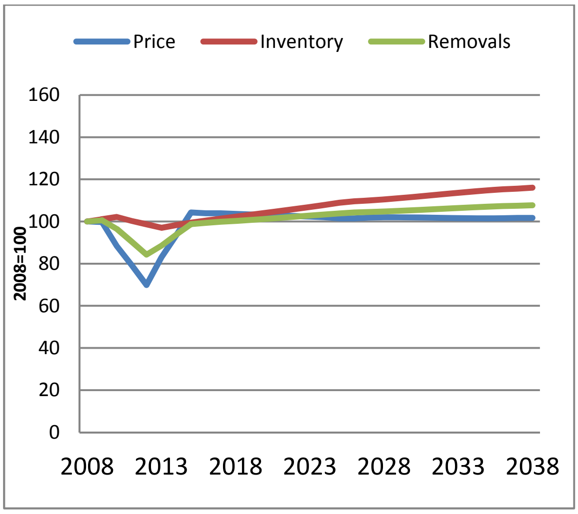


c) B2 scenario

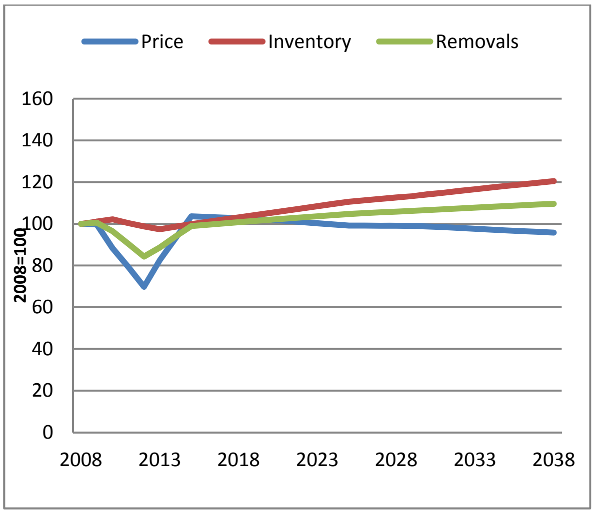


d) C2 scenario

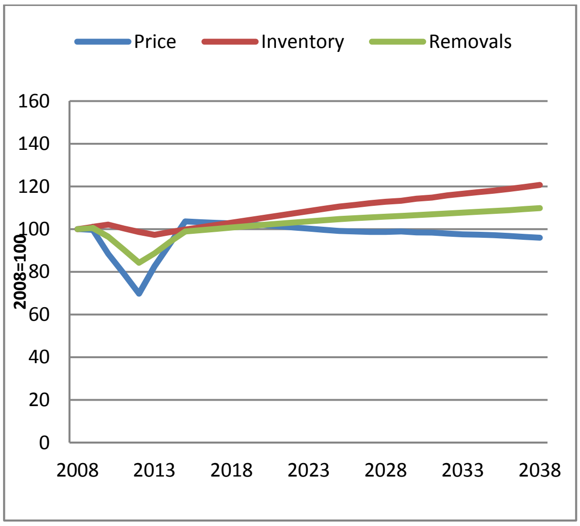
Appendix H. Hardwood sawtimber- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for Southeastern U.S. between 2008 and 2038



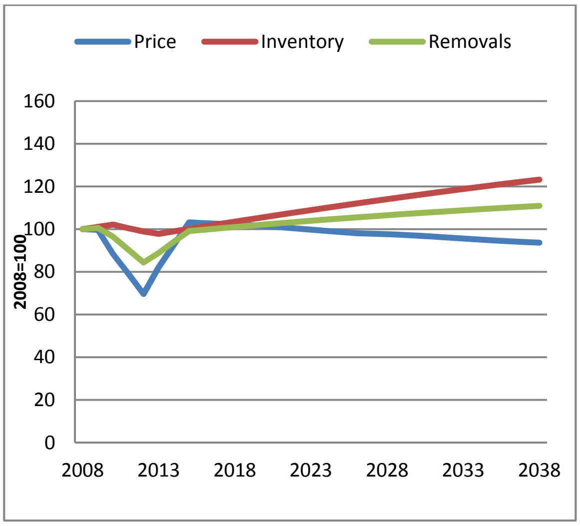
a) Baseline: traditional demand with no bioenergy



b) A2 scenario

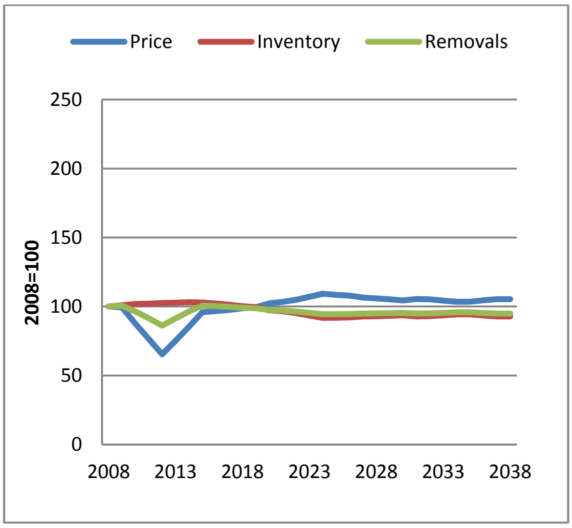


c) B2 scenario

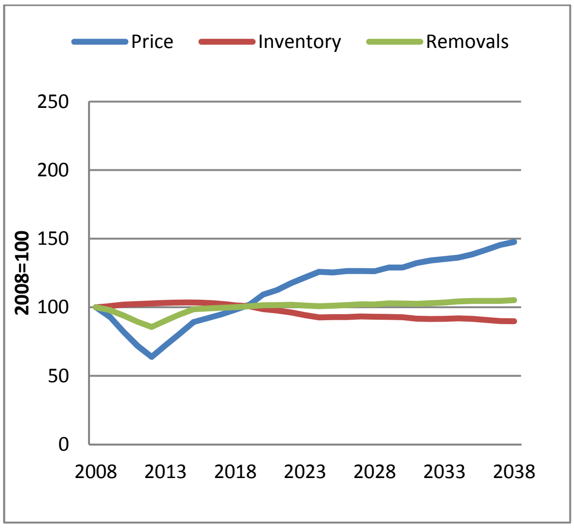


d) C2 scenario

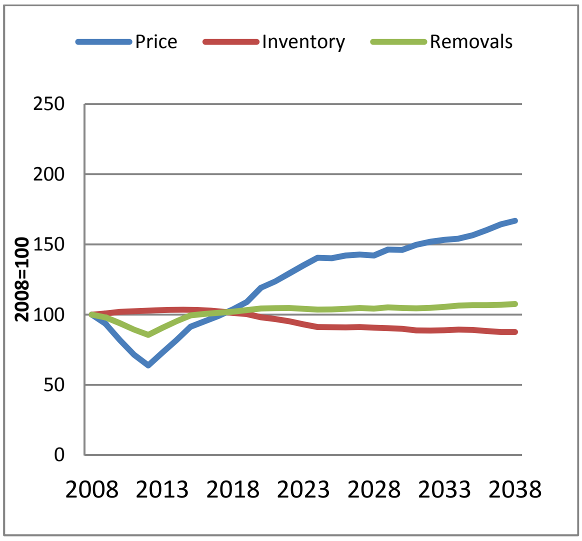
Appendix I. Softwood pulpwood- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for the coastal States' of Southeastern U.S. between 2008 and 2038



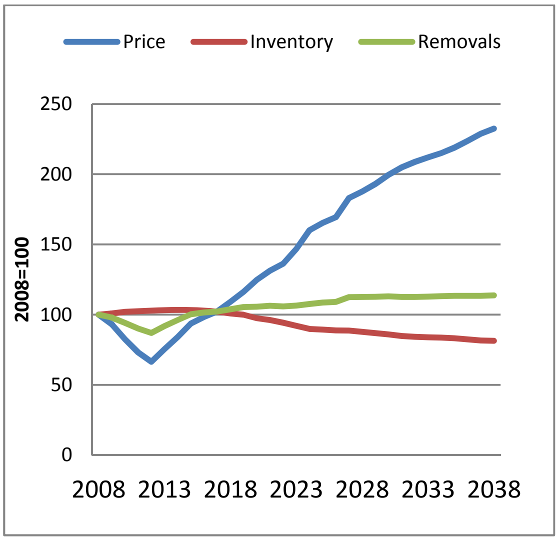
a) Baseline: traditional demand with no bioenergy



b) A2E scenario

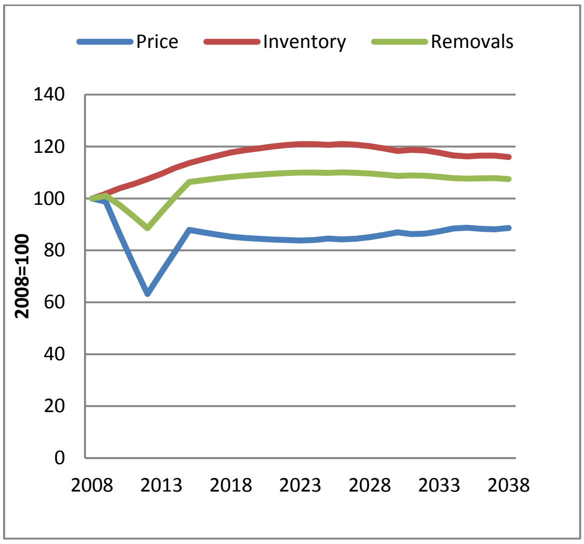


c) B2E scenario

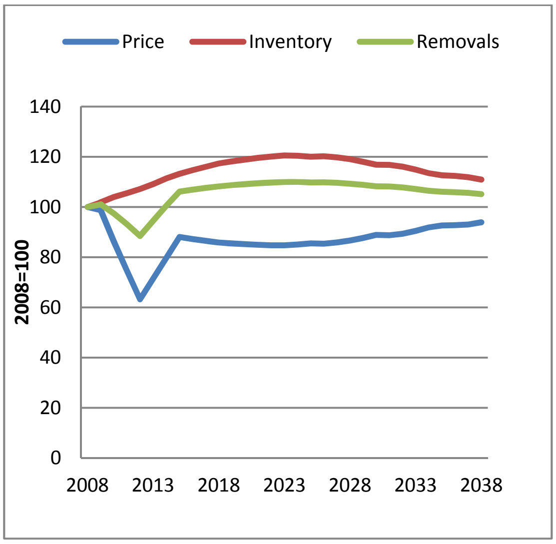


d) C2E scenario

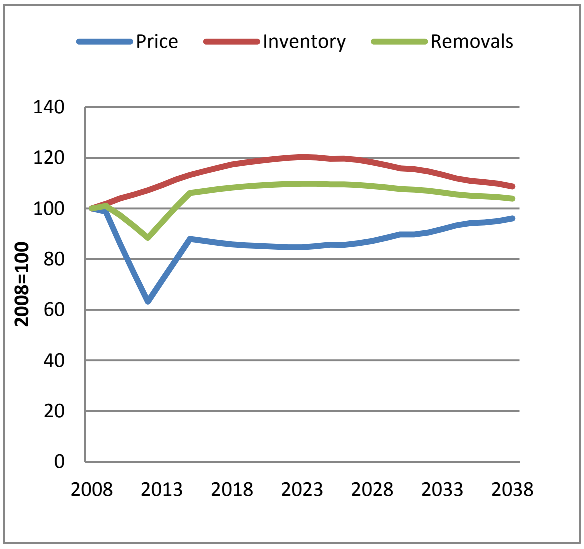
Appendix J. Softwood sawtimber- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for the coastal States' of Southeastern U.S. between 2008 and 2038



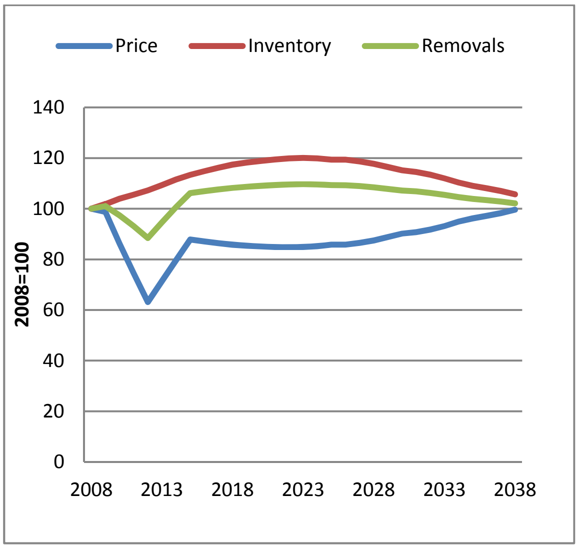
a) Baseline: traditional demand with no bioenergy



b) A2E scenario

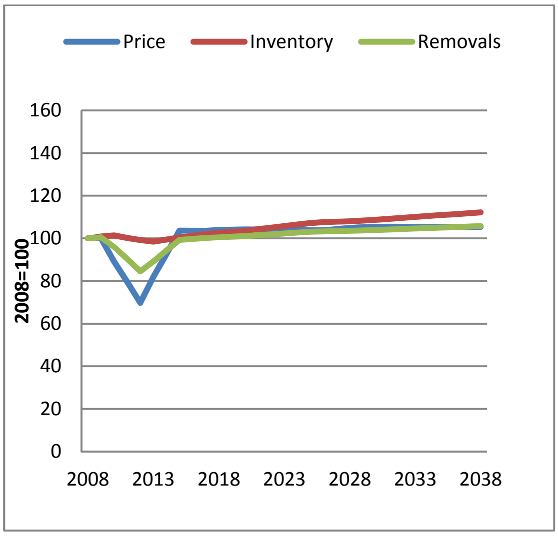


c) B2E scenario

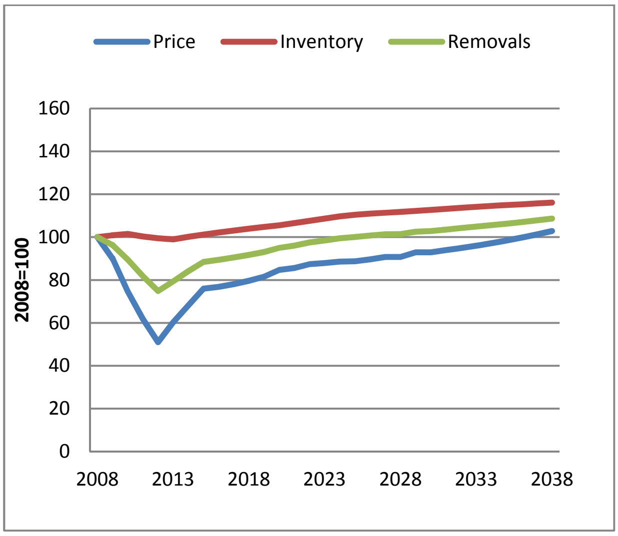


d) C2E scenario

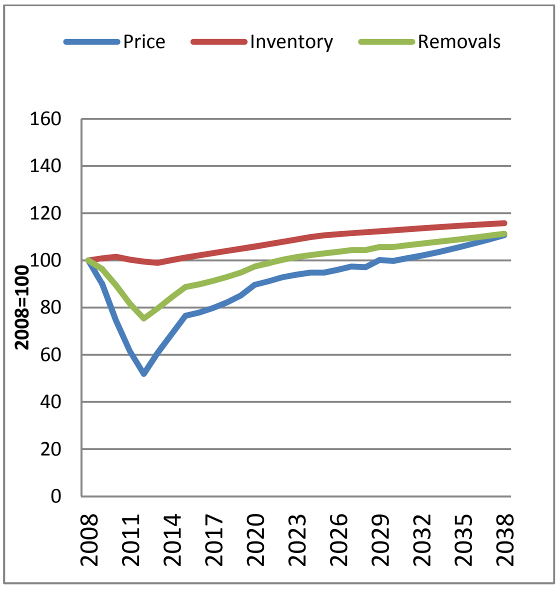
Appendix K. Hardwood pulpwood- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for the coastal States' of Southeastern U.S. between 2008 and 2038



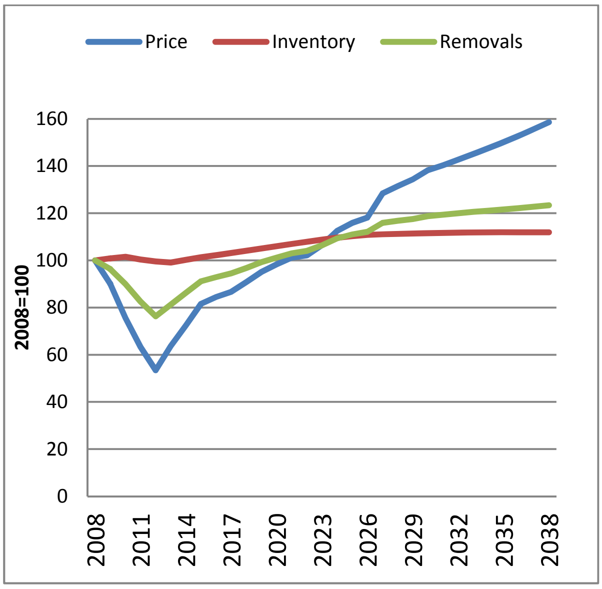
a) Baseline: traditional demand with no bioenergy



b) A2E scenario

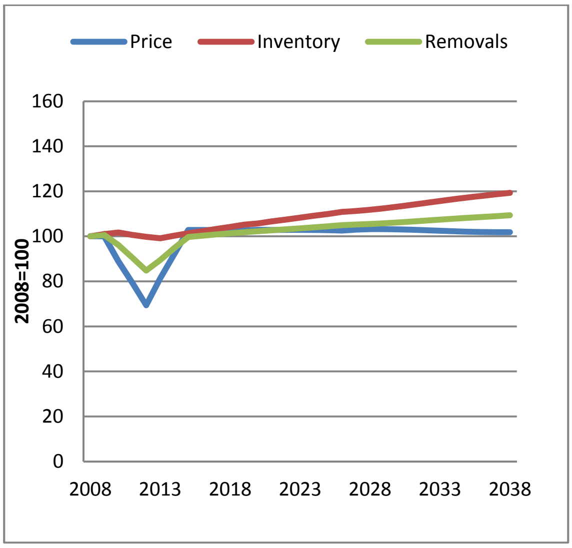


c) B2E scenario

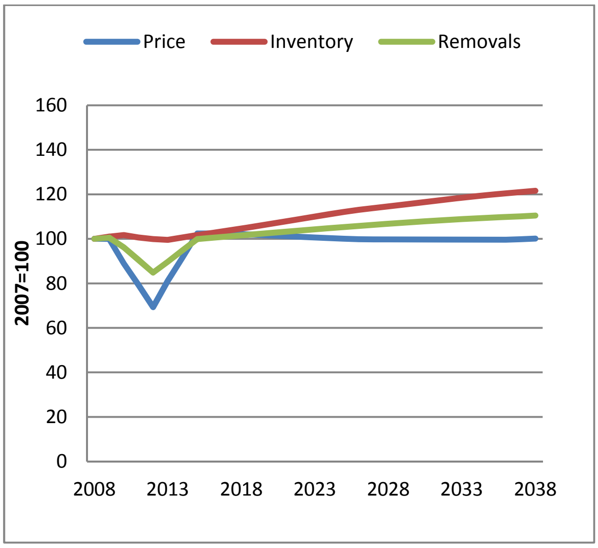


d) C2E scenario

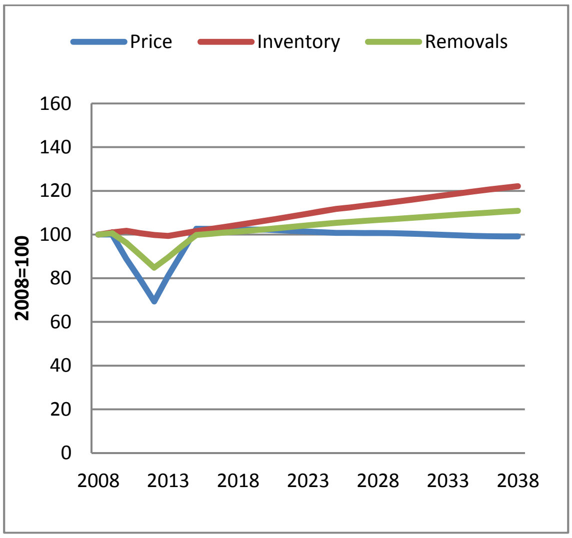
Appendix L. Hardwood sawtimber- comparison of prices, inventory and removals for the baseline and bioenergy scenarios for the coastal States' of Southeastern U.S. between 2008 and 2038



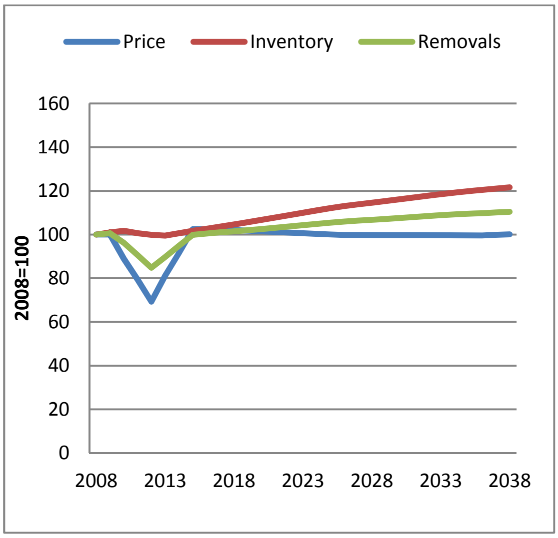
a) Baseline: traditional demand with no bioenergy



b) A2E scenario



c) B2E scenario



d) C2E scenario