WHERE IS THE MONEY? – VALUE FLOWS IN THE PRESENT SWEDISH FOREST-BASED SECTOR

Report from an f3 project

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Authors:

Jonas M Joelsson
SP Processum AB

Dimitris Athanassiadis
Swedish University of Agricultural Sciences

THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report is the result of a collaborative project within the Swedish Knowledge Centre for Renewable Transportation Fuels (f3). f3 is a networking organization, which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities,
- Carries through system oriented research related to the entire renewable fuels value chain,
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

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SUMMARY

The intensified focus on bio-based economy has revived the interest in forest industry as a very important factor in the achievement of the transition away from an economy based in fossil raw materials. The sustainable use of the natural resources and their ecosystem services is an important constituent of the bioeconomy. The objective of the present study is to give an overall view of the economic values related to the main physical biomass flows through the Swedish forest industry and to discuss the implication for these value flows at the introduction of large-scale transportation fuel production from forest biomass. Thereby it aims to provide a better understanding for the bioeconomy structure, the values added within it and the options for renewable motor fuel production, by applying a “follow-the-money”-approach.

The approach has been to combine existing information on physical feedstock flows with economic data from available statistics and literature. The results of the value flow analysis are graphically illustrated with Sankey diagrams. More detailed data on production, market prices and value chains were compiled for selected products (softwood kraft pulp, dissolving grade cellulose and ethanol) through interviews and collection of more detailed statistics.

Sawlogs and pulpwood account for approximately equal shares of the harvested roundwood volume (29700 Mm^{3}sub sawlogs and 28000 Mm^{3}sub pulpwood in 2009), whereas the value at roadside of the sawlogs is considerably higher (15500 MSEK vs 9200 MSEK in 2009). Adding that it is less costly to harvest and handle coarser logs than thinner logs, the sawlogs appear as the, clearly, most profitable product from the forest owners perspective. The total value of logging residues at roadside in 2009 was about 1100 MSEK, or about 4% of the total forest product value at roadside. About half of the logging residue value at roadside was spent on harvest and forwarding, whereas the corresponding value for roundwood is about a quarter.

Sweden is a large net exporter of wood and products of wood as well as of paper and products of paper. The forest feedstock value as a share of the export value is larger for wood and wood products than for paper and paper products, indicating that the latter products require more (domestic) processing and hence contribute positively to added value and trade balance. The Swedish export of “Furniture and other manufactured goods” is approximately balanced by an equally large import.

Different processing routes are interlinked. For example, the flow of by-products from sawmills to pulp industry represents a significant value. Biorefining with integrated production of several products is generally found to be more efficient and with better economic performance than separate production. Integration with interdependence of several processes, however, increases the technical complexity and puts new demands on the businesses. Integration of motor fuel production in a pulp mill means that the forest industry company either has to embark into a completely new area of business, or to let another actor closely into their own core activities. Also changes on the feedstock supply side could require important changes in business models. An integration of stemwood and logging residues has the potential to reduce the total supply cost, but it would imply that the (at present) low-value residue product is allowed to interfere with the (at present) high-value stem-wood product.

In general, forest-based motor fuel faces a number of challenges. The feedstock cost is relatively high, partly as a result of competition from other industries (sawmills, pulp mills, heat and power

plants) and partly as a result of slow-growing wood and high processing and transportation costs. The processes for conversion of wood into motor fuel are, hitherto, relatively complex and expensive, compared to, for example, the processes for converting sugar, starch and oil crops into motor fuel. The feedstock basis is large, but there seems to be some development remaining for the processes to run efficiently and reliably on more difficult feedstock, such as logging residues and bark. Finally, petroleum-based fuels remain cheap, relative to the present production costs of forest-based fuels.

Motor fuel production from forest resources appears more likely to emerge as a by-product to other products, which make better use of the unique properties of boreal forest. The feedstock could appear in the forest as logging residues, but also as side streams in other forest-based industries. A higher degree of processing of wood (more selective and adapted sawmilling, processing of wood into furniture etc., or a higher degree of pulp refinement etc.) is likely to yield more residues available for, for example, energy purposes. Hence, there is a possible synergy between development of higher-added-value products from wood and utilization of residues for other purposes, such as motor fuel.

New developments on the by-product side of motor fuel production could also alter the situation. If a high-value application were to be found for hydrolysis lignin, for example, this could improve the attractiveness of the ethanol process, although motor fuel might become the by-product and other value-added streams the main product.

We suggest that biorefining is about finding the optimal combination of feedstock requirements, processing cost, process flexibility, product mix and product properties. It should, however, be noted that each new product and process stream entails costs and adds complexity - of technical as well as organizational nature.

SAMMANFATTNING

Denna rapport syftar till att ge en översiktlig bild av de ekonomiska flödena genom den skogsbaserade ekonomin i Sverige. Därigenom avser den att öka förståelsen för bioekonomins struktur, för värdeskapandet inom den samt för förutsättningarna för storskalig produktion av skogsbaserade drivmedel.

Ansatsen har varit att kombinera statistiska data för fysiska råvaru- och produktflöden med ekonomiska data från den offentliga statisktiken och litteraturen. Resultaten presenteras grafiskt i så kallade sankey-diagram. Mer detaljerade uppgifter om produktion, marknadspriser och värdekedjor sammanställdes för tre utvalda produkttyper (barrsulfatmassa, dissolvingcellulosa och etanol), genom intervjuer och mer detaljerade litteratursammanställningar.

Sågtimmer och massaved står för ungefär lika stora delar av den avverkade stamvedsvolymen, men det ekonomiska värdet av sågtimret är betydligt högre än värdet av massaveden (ca 15500 MSEK jämfört med 9200 MSEK år 2009). Massaveden medför dessutom dyrare avverkning och hantering, och sågtimmer framstår som det klart mest lönsamma sortimentet för skogsägaren. Värdet av energisortiment i form av grot var ungefär 1100 MSEK 2009, eller omkring 4% av det totala värdet av produkter från skogsbruket. Kostnader för skörd och skotning motsvarar ca halva värdet vid bilväg för grot. Motsvarande siffra för rundvirke är omkring en fjärdedel.

Sverige är en stor nettoexportör av trä och träprodukter liksom av pappers- och massaprodukter. Råvarans värde som andel av exportvärdet är mindre för pappers- och massaprodukter än för trävaror, vilket visar på den större grad av förädling som görs nationellt av pappersprodukter. För högt förädlade träprodukter, som t.ex. möbler, är den svenska importen ungefär lika stor som exporten.

Olika processvägar är sammanflätade, och biprodukter från en process kan användas som råvara i andra processer. Samproduktion av flera produkter i bioraffinaderier förefaller generellt sett vara mer effektivt än separat produktion, men man bör också beakta att komplexiteten ökar då fler processer och produkter ska hanteras samtidigt. Integrering av drivmedelsproduktion med t.ex. befintlig massaindustri innebär ökad komplexitet och kan kräva nya affärsmodeller för den befintliga industrin.

Drivmedelsproduktion från skogsråvara har ett antal utmaningar. En är att råvaran är förhållandevis dyr, delvis beroende på konkurrens från andra industrier (sågverk, massabruk och värmeverk) och delvis beroende på att den svenska skogen är en relativt långsamt växande råvara med höga avverknings- och hanteringskostnader. Processerna för att omvandla trä till drivmedel är, än så länge, relativt komplexa och dyra. Råvarubasen är stor, men en del utvecklingsarbete tycks kvarstå för att processerna effektivt ska kunna hantera mer komplicerade råvaror som grot och bark.

Skogsbaserade drivmedel kanske har bäst möjlighet att realiseras som en biprodukt till andra produkter, som bättre utnyttjar barrvedens unika egenskaper. Råvaran till drivmedel skulle kunna vara avverkningsrester eller andra industriella biströmmar. En högre bearbetningsgrad av vedråvaran till trä- och fiberprodukter ger sannolikt ett större utfall av restprodukter. Det kan därmed finnas en synergi mellan högförädlade produkter och användning av biprodukter för andra ändamål, såsom drivmedel.

Utveckling av nya produkter och marknader baserade på biprodukter från drivmedelstillverkning kan också påverka förutsättningarna för drivmedelsproduktion. Om t.ex. mer högvärdiga applikationer utvecklas för hydrolyslignin kan det förbättra utsikterna för etanolproduktion från vedråvara.

Sammanfattningsvis vill vi påstå att effektiv bioraffinering handlar om att hitta den optimala kombinationen av råvarukrav, processkostnad, processflexibilitet, produktmix och produktegenskaper. Därvid bör man också beakta att varje ny produkt eller process medför ökade kostnader och ökad komplexitet – av både teknisk och organisatorisk natur.

ABBREVIATIONS

ARA	Amsterdam-Rotterdam-Antwerp area – a port and refining area in the Belgian-Dutch region.
CHP	Combined heat and power
CIF	Trade price including Cost, Insurance and Freight
FOB	Free On Board
HHV	Higher Heating Value
kgDM	kilogram Dry Matter
kt	1000 metric tons
LWC	Light-Weight Coated paper
m^3l	cubic metre loose material
m^3sk	cubic metres standing volume (stem volume over bark from stump to tip)
m^3sub	cubic metres solid volume excluding bark
m^3sw	cubic metres sawn wood
Mm^3	million cubic metres
MSEK	million Swedish Kronas
MTO	Methanol-To-Olefins
NBSK	Northern Bleached Softwood Kraft
NG	Natural Gas
SC	Super Calendered
SEK	Swedish krona
SNG	Synthetic Natural Gas
t	metric ton
tDM	metric ton Dry Matter
tpy	metric ton per year

CONTENTS

1. INTRODUCTION

The intensified focus on climate change and the sustainable use of resources has revived the interest in forest industry as a very important factor in the transition from an economy based in fossil raw materials to a bioeconomy, based on renewable raw materials. To accomplish this transition, large changes of the energy systems on both global and local scales are necessary. A larger share of nationally available, renewable sources in the energy supply is also important to increase energy security and reduce dependence on imported energy sources such as oil and coal. Currently forest biomass is used as raw material mainly for production of sawn products and pulp and paper, which are used on a national market or exported worldwide. Waste-products from forest industries are to a high extent utilized for e.g. heat and electricity production on a national market. This has led to an increasing utilization of residual forest biomass extracted directly from the forest, such as branches and tops and stumps from clear-cuttings, small diameter trees from early thinnings and low value round wood.

1.1. OBJECTIVE

The objective of the present study is to give an overview of the economic values related to the main physical biomass flows through the Swedish forest industry and to discuss the prospects for introduction of large-scale transportation fuel production from forest biomass. Thereby it aims to provide a better understanding for the bioeconomy structure, the values added within it and the options for renewable motor fuel production, by applying a “follow-the-money”-approach. The method has been to combine existing information on physical feedstock flows with economic data from available statistics and literature.

1.2. THE FOREST-BASED INDUSTRY

The forest industry is defined by the Swedish Forest Industries Federation to include the pulp and paper industry, sawmill industry, wood board industry, production of packaging from wood, paper and board, as well as the carpentry industry and the industry for manufacture of refined wood fuel. The scope of this report is, in addition to the forest industry, also the forestry sector, which produces and supplies forest feedstock to the industry.

The wood feedstock can be converted by means of several different processes. Figure 1 show main existing (black labels) and developing (green labels) conversion pathways. They can be roughly grouped into mechanical, chemical and thermochemical pathways.

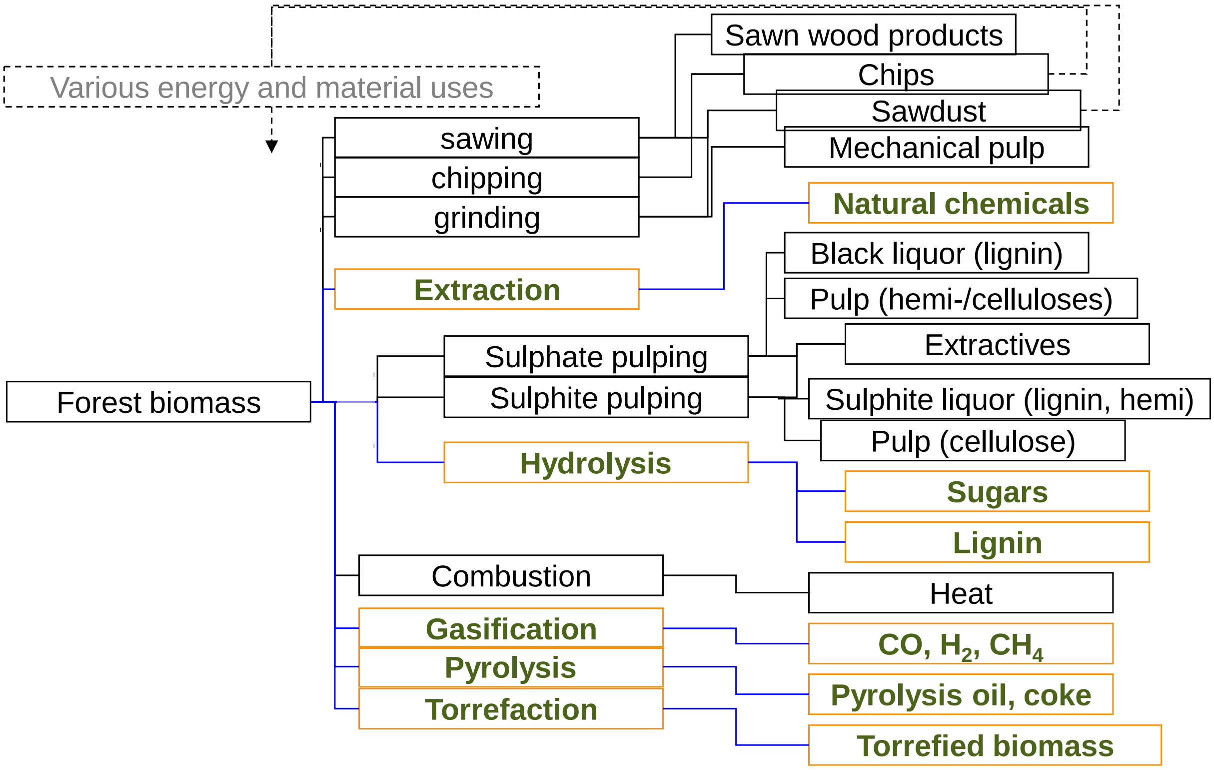


Figure 1. Pathways for forest biomass conversion.

1.2.1. Forest feedstock production and supply

Sweden's land area is 40.8 million hectares of which 28.1 million hectares are forest land. The majority of this (23.3 million hectares) is productive forest, which is the dominant land use class, followed by alpine areas (5.2 million hectares), mires (5.1 million hectares) and agricultural land (2.9 million hectares) (Swedish National Forest Inventory, 2015).

The total standing forest volume in Sweden has increased significantly through the past 100 years. In the mid 1920's the total standing volume was 1719 million m³sk and 2014 it was just over 3398 million m³sk or approximately 2500 million metric tons dry matter (tDM). Sweden's forests are dominated by spruce (40%) and pine (40%). The age distribution is such that the most common forest age group is 41-60 years. Many species are connected to old forest and there are approximately 3 million hectares of forest older than 140 years which represents ca 11 percent of the forest land area. This type of forest is most common in Norrland where it is a significant proportion of the forest land area (approximately 18% in northern Norrland and 14% in southern Norrland). In southern Sweden there is little forest land with an age over 140 years (Swedish National Forest Inventory, 2015).

Felling activities, primarily pre-commercial thinning, commercial thinning and final felling affect a relatively small proportion of Sweden's forest area each year. Felling volumes, both in absolute terms and per hectare is highest in Götaland and lowest in northern Norrland. The annually felled volume for the period 2008/09 - 2012/13 was 80 million m³sk on average. Final felling accounted for the largest share of the felled volume (56%). In terms of area, thinning is the most common felling activity (380 000 hectares annually), followed by cleaning (260 000 hectares annually) and final felling (198 000 hectares annually). Spruce represents 52% of the felled volume. Pine represents 32% of the felled volume, slightly lower than its share of the standing volume (40%).

The remaining felled volume is made up of broadleaved trees (16%) (Swedish National Forest Inventory, 2015).

The productive forest land in Sweden is owned by 330000 forest owners, distributed as shown in Figure 2. In 2012, the number of forest entities (owned by single owners) was 229802, of which 68% were locally owned, 25% were owned by non-residents and 7% owned partly by non-residents.

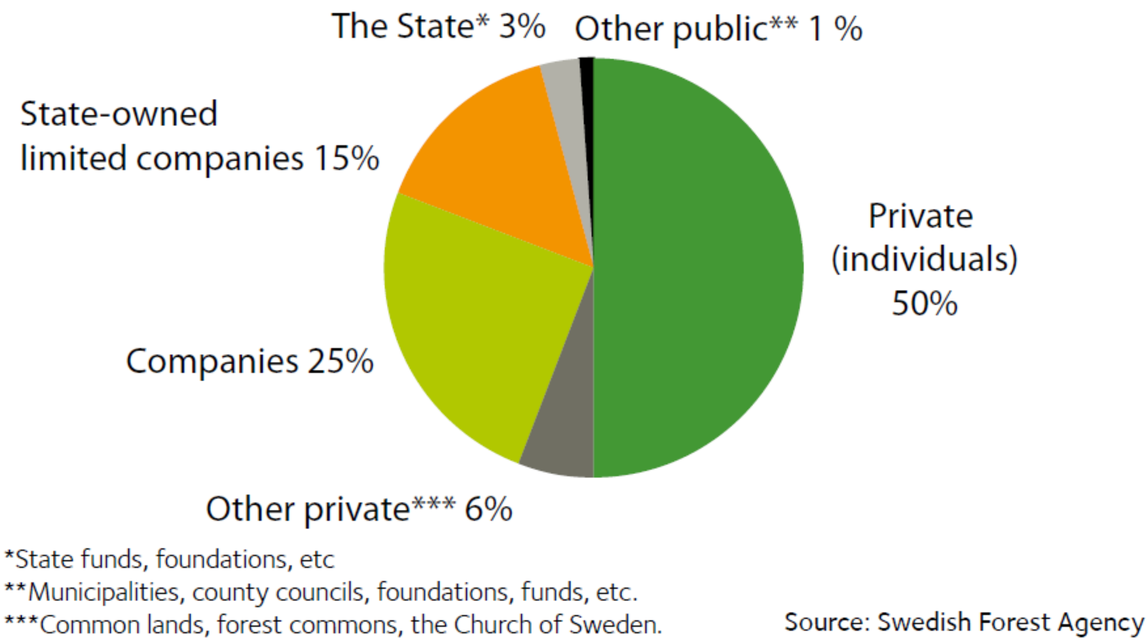


Figure 2. Breakdown of Swedish productive forests by type of ownership (Swedish Forest Industries Federation, 2012a).

1.2.2. Sawmill industry

The Swedish sawmill industry consists of two main categories of sawmills. Partly sawmills that are part of large forest industries (e.g. SCA and Södra) which produce sawn wood alongside with the production of pulp and paper and other products and partly sawmills that are not linked to other industry. In 2013, 16 million cubic meters (Mm^3sw) of sawn softwood were produced (Skogssverige 2015). Production of sawn wood in Sweden is shown in Figure 3.

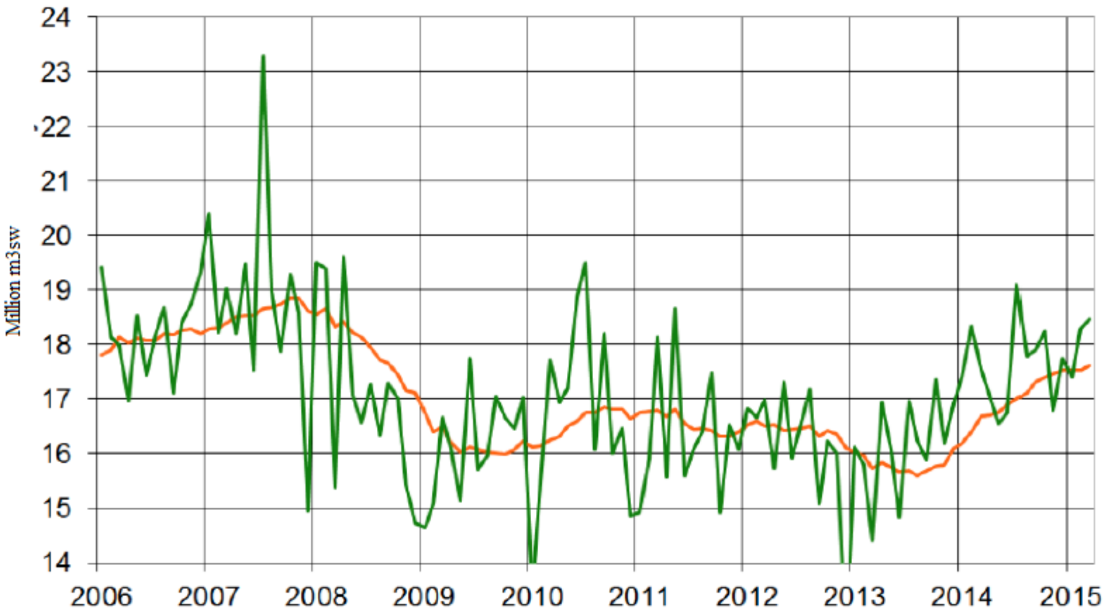


Figure 3. Production of sawn wood in Sweden from 2006 until May 2015 (Swedish Forest Industries Federation, 2015b).

1.2.3. Pulp and paper industry

In 2013, there were a total of 51 pulp mills and paper mills in Sweden. 11.7 million tonnes (Mt) of paper pulp was produced, of which 7.6 Mt sulphate pulp, 3.5 Mt semi-chemical and mechanical pulp and 0.6 Mt sulphite pulp. 10.8 Mt of paper and paperboard were produced (Figures 4 & 5), of which 1.6 Mt newsprint, 3.3 Mt printing paper, 0.9 Mt packaging paper, 1.9 Mt corrugated paper, 2.6 Mt cardboard for packaging and 0.4 Mt other paper and paperboard (Skogssverige 2015).

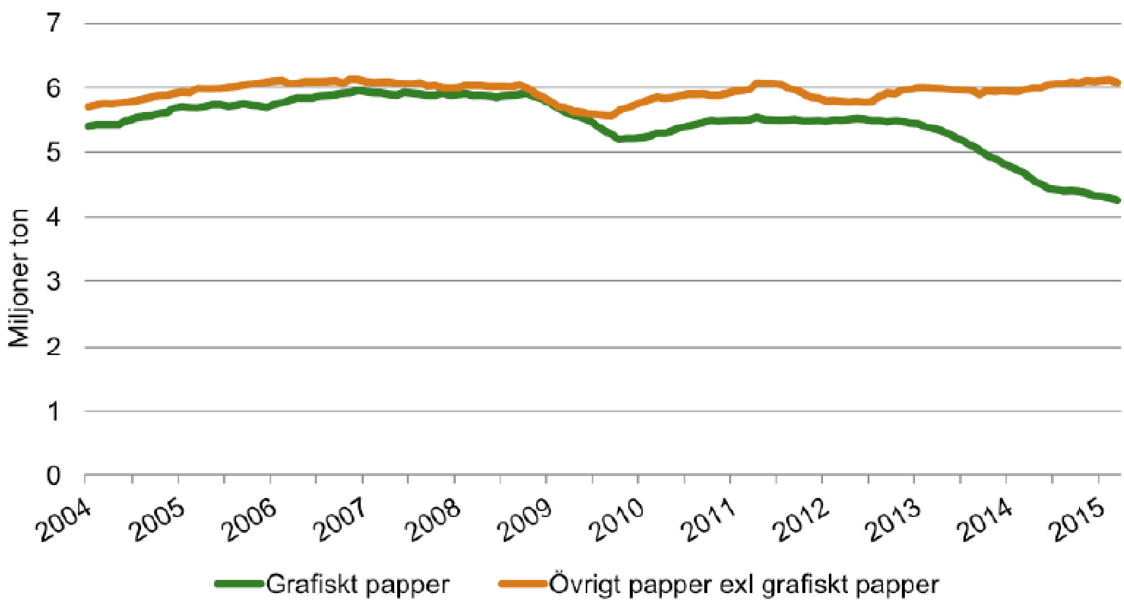


Figure 4. Production of paper in Sweden from 2004 until April 2015 (Swedish Forest Industries 2015b).

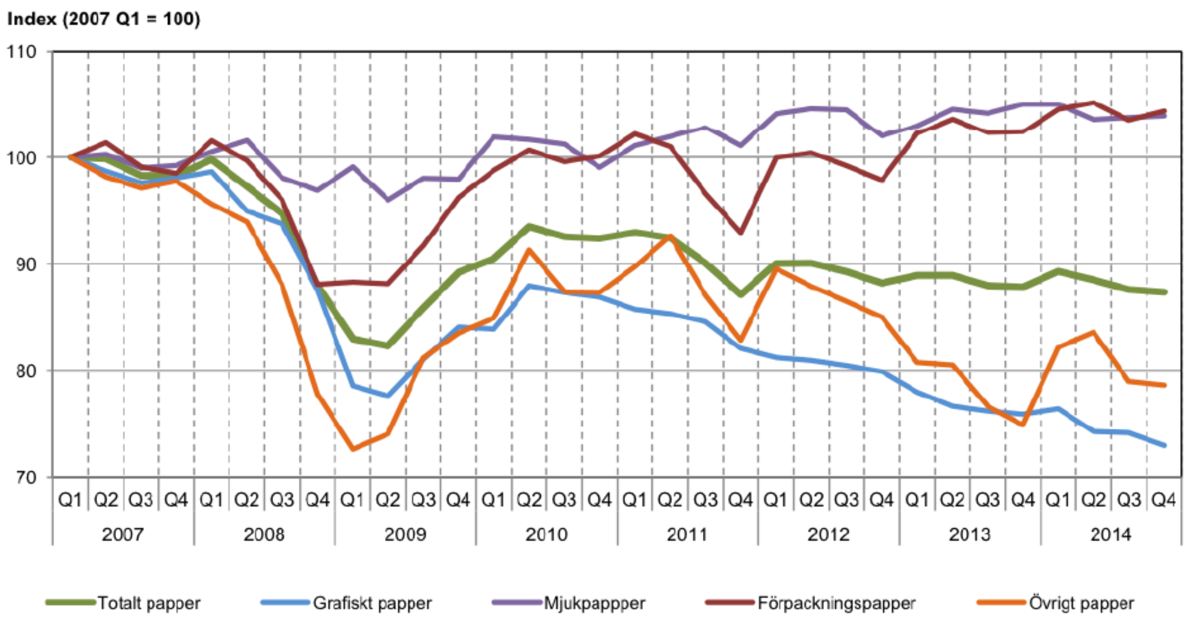
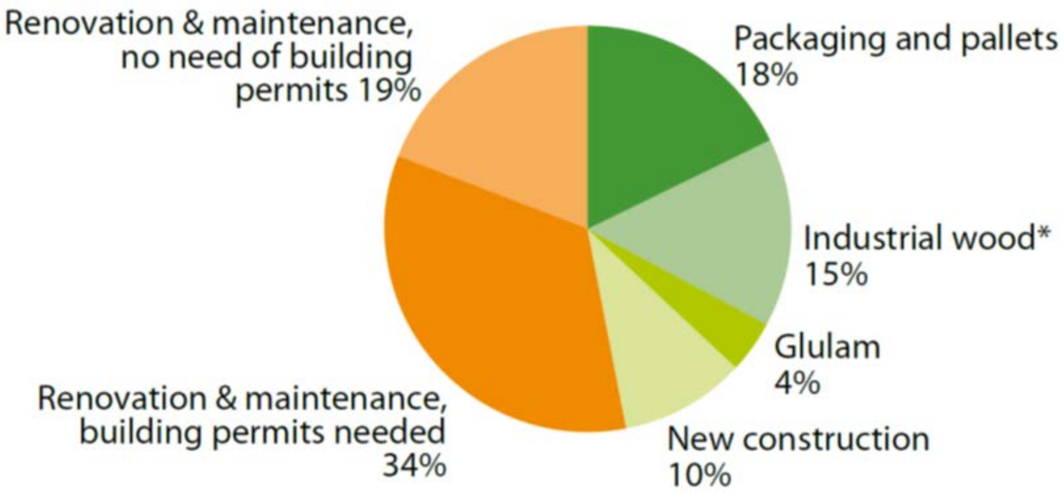


Figure 5. Production of different qualities of paper from CEPI member companies (2007-2014) (Swedish Forest Industries 2015b).

1.2.4. Wood manufacturing and board industry

Wood manufacturing and board industry includes wood refining industries, for example, producers of wooden houses, building components (doors, window frames, etc.), furniture, interior components and wood products such as wood-based board and glulam beams. The Swedish consumption of sawn softwood was approximately 5.4 Mm^3 in 2011. The largest use was in renovation and maintenance applications (53%) followed by use for packaging (boxes etc.) and pallets (18%) (Figure 6).



*) Wood to industries manufacturing flooring, furniture, windows, doors, stairs or components for such products.

Figure 6. Estimated sawn softwood consumption in Sweden 2010, by area of application. The total volume consumed was approximately 5.4 Mm^3, Swedish Forest Industries Federation, 2012a).

1.2.5. Forest-based energy industry

Forest is the largest source of raw material for the generation of bioenergy. By-products from sawmills (such as bark , sawdust and wood chips), pulp mills (spent pulping liquors, bark) and from forest operations (branches and tops, stumps and rejected roundwood) are used for the production of energy in about 400 heat plants and combined heat and power (CHP) plants.

1.3. RELEVANCE FOR FUTURE MOTOR FUEL VALUE CHAINS

The energy use for domestic transport in Sweden in 2013 was 92 TWh. Gasoline and diesel (excluding blended ethanol and biodiesel) accounted for 32 and 45 TWh of the energy use, respectively. In total, road transport accounted for 94% of the domestic transport energy use (Swedish Energy Agency, 2014a). If forest feedstock is converted to motor fuel at 50% efficiency on energy basis, 144 TWh of feedstock would be required to replace all of the Swedish gasoline and diesel use at the 2013 level. This should be compared to an estimated 170 TWh of industrial forest feedstock and 25 TWh of primary forest fuel currently extracted per year (Swedish Forest Industries, 2015a). To replace a large share of the present motor fuel use with domestic forest-based fuel would, hence, require a feedstock flow with a significant magnitude, relative to the present forest feedstock flows. A good understanding of the present flows may be useful in assessing opportunities and consequences associated with large-scale production of forest-based motor fuel.

There are several possible pathways from forest feedstock to final motor fuels, some of which were studied in the recently ended project Skogskemi (Joelsson et al., 2015). The following sections briefly describe some of the value chains included in the Skogskemi project, which we will later compare to value chains of the existing forest-based industry.

1.3.1. Value chains of the Skogskemi project

Figure 7 gives a schematic overview of the value chains studied within the Skogskemi project. The objective of the project was to study pathways from forest to drop-in chemical products. However, several of the chemicals included as final or intermediate products are also potential motor fuels, such as ethanol, methanol and butanol.

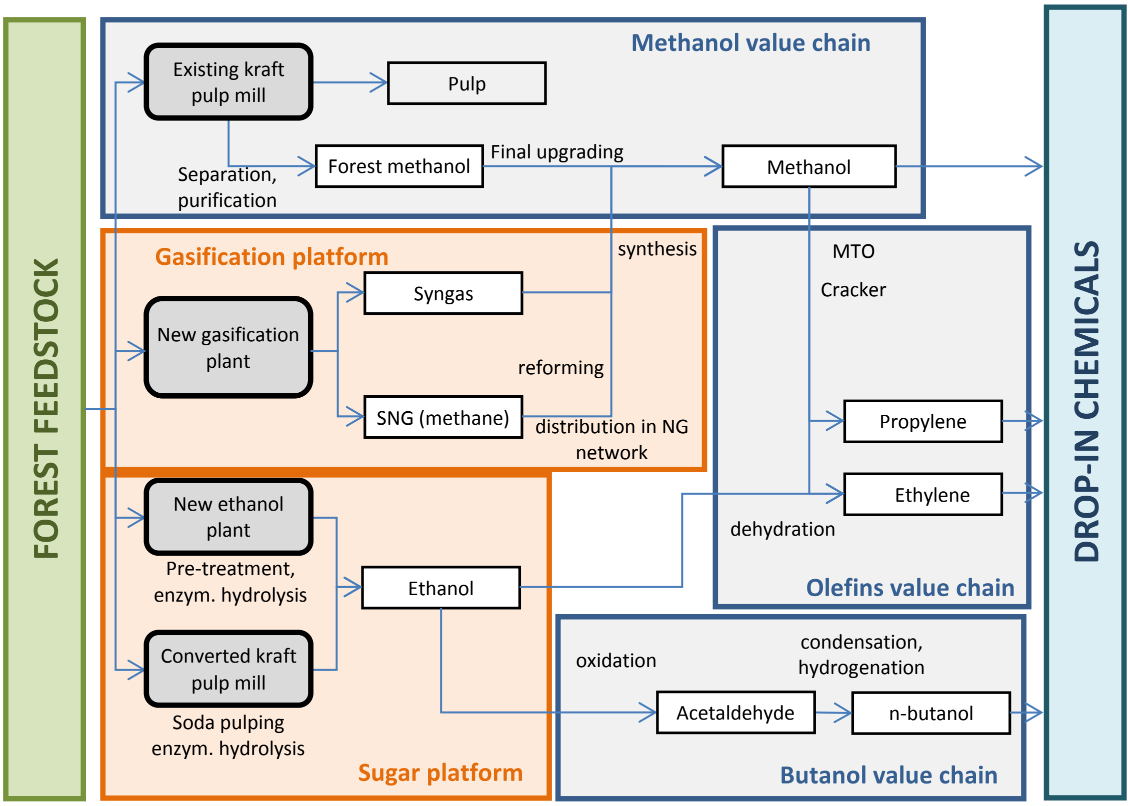


Figure 7. Overview of Skogskemi platforms and value chains (Joelsson et al., 2015)

1.3.2. Ethanol

Forest-based ethanol was a key intermediate in the Skogskemi project. Ethanol is presently produced mainly through fermentation processes using starch- and sugar-based feedstock. A smaller amount of ethanol is also produced synthetically from ethylene. Industrial ethanol production from wood has been performed historically, but new technologies are, however, expected to have superior performance. These new technologies, which utilize lignocellulosic feedstock such as wood, and enzymatic treatments are currently in the phase of large-scale demonstration on several sites globally. A key step in the processes is saccharification – the conversion of feedstock into fermentable sugars. Saccharification of lignocellulosic feedstock requires pretreatment. The chemistry based on the further conversion of the sugar molecules into a range of chemicals and materials is collectively called the sugar platform.

The Skogskemi sugar platform studied processes based on conversion of forests-based feedstock to ethanol through thermochemical pretreatment, saccharification, fermentation, dewatering and purification. Issues regarding co-products, logistics, integration possibilities, market and cost evaluations were also included.

1.3.3. Methanol

Methanol production via gasification of biomass is one of the main, large-scale, pathways considered in the discussion on alternative fuels and chemicals. This pathway was explored in the gasification platform subproject of Skogskemi. By gasification, lignocellulosic biomass is transformed to a gas. Hydrogen, carbon monoxide and methane are typically key components of the gas, which could be combusted for heat and power generation or cleaned and conditioned to be used for the synthesis of a large number of hydrocarbon compounds. In the latter case, the gas is called a syngas. Methanol is one of the products that could be synthesized from the syngas. Down-stream processes where syngas is synthesized into methanol are commercially available processes and exist in large scale plants where fossil raw material is used.

1.3.4. Butanol

Butanol is a chemical used in both water-based and oil-based paints. Today butanol is produced from fossil feedstock and the global production is about 3 000 000 tonne per year (tpy). Biobutanol can also be used as a biofuel to replace diesel. Both car engine manufacturers and oil companies are today interested in biobutanol as a diesel component blended in up to 30% in diesel. Butanol could be produced from biomass directly via fermentation or via catalytic processes. The pathway pursued in Skogskemi is to produce butanol via biomass-based ethanol, a process for which there is well proven technology.

1.4. RELATED WORK

The forest industry sector is important in the Swedish economy, and its structure and economics have been studied from many perspectives. A few of these studies are described in this section.

1.4.1. Mapping of forest-based flows

Nilsson (2006) gives an overview of the flow of forest biomass on productive forest land to the industry in Sweden in 2004. These values are later updated by Anderholdt Helgesson et al. (2012) where statistics for 2009 were utilized. According to these studies the sawmill industry consumed 34.6 million m^3sub (solid cubic meters excluding bark) of roundwood in 2004 (33,4 million m^3sub in 2009) while the pulp industry consumed 27.8 million m^3sub of roundwood in 2004 compared with 29 million m^3sub in 2009, an increase of 5%. The Swedish forest-based raw material flows have also been reviewed and illustrated recently by Staffas et al. (2015). Mantau (2012) reviewed the European wood flows.

1.4.2. Value added in forest-based value chains

The forest biomass value chain includes many actors that cooperate and together ensure the delivery of forest biomass to the users (Teischinger 2009). Those can be for example forest owners, forest management consultants, logistic companies and contractors. For every step of the value chain (planning, forest operations, road construction and maintenance, and road transport of roundwood and logging residues) the value of the forest biomass increases. The actors are expected to exchange information with each other in order to make the chain more efficient and maximize their profits. The actors face social, environmental, economic and operational constraints that make the value chain more complex.

Götherström (2007) showed that the use of pulpwood in the mechanical pulp industry for the production of newsprint had a bigger effect on employment, added value and export value compared to its use for the production of heat and power in CHP-plants. Wirén (2008) compared value chains for the heat market, including biofuel supply to heat plants and wood pellet boilers.

Sathre and Gustavsson (2009) developed a bottom-up method to estimate the value added by forest industry processes and calculate the value added by 14 traditional and emerging processes within the Swedish forest products industries. Structural wood products such as lumber and glue-laminated beams were found to give the greatest value added and co-production of multiple products from a single raw material increased total value added.

From the forest-owner perspective, Thörnqvist (2007) found that saw timber generated about 80% of the net harvest income and pulpwood only 20%, with logging residues accounting for a mere 0.7%. According to Holmberg (2013) about 20% of the harvested wood ends up as sawn wood, 30% as pulp and 50% as energy. Approximate value addition in wood-mechanical industry was given, with the lowest values for construction (about 1.5 times the sawn-wood value) and the highest values for furniture and other carpentry applications (20-30 times the sawn-wood value).

1.4.3. Economic modelling

Economic modelling and optimization typically aims at identification of system solutions that maximize the generated value or minimize the costs, under given constraints. The f3 project BeWhere is an example of this type of study (Wetterlund et al. 2013a,b). The BeWhere project studied how renewable fuel targets could be achieved in Sweden, and where biofuel production plants would optimally be located, by means of a model that minimizes the cost of the entire studied system, including costs and revenues for biomass harvest and transportation, production plants, transportation and delivery of biofuels, sales of co-products, and economic policy instruments. It is found that the implementation of next generation biofuel production could require a significant increase in the use of forest residues (branches, tops and stumps), from the 14 TWh currently used annually, to 32-50 TWh/year (depending on biofuel target and biomass use in other sectors).

2. METHODOLOGY

In the project we collected and compiled existing market and forest industry production statistics on timber and pulpwood as well as on forest industry products and on several energy assortments (logging residues, stumps, young trees from pre-commercial thinnings and energy wood).

The general approach in data collection comprised of three levels of information:

- Level one: Overview based on national accounts.
- Level two: Aggregated values for key flows and product groups, based on published market data, trade statistics, stakeholder interviews and assumptions.
- Level three: Increased detail for certain products.

2.1. AVAILABLE DATA SOURCES

Several private and public organizations publish statistics related to the forest-based economy. A number of the most important ones are shortly described in the following section.

2.1.1. Swedish forest agency

The Swedish Forest Agency is the national authority in charge of forest-related issues with the main function to promote the kind of management of Sweden's forests that enables the objectives of forest policy to be attained. Much of the national statistics related to forestry and use of forest resources are compiled by the Swedish forest agency in their annual publication “Statistical yearbook of forestry”, and there is also some additional data published on their website (Forest Agency 2015).

2.1.2. Swedish forest industries federation

The Swedish Forest Industries Federation is the trade and employers’ organisation for the pulp, paper and wood mechanical industries. The Federation represents around 50 pulp and paper manufacturers in a total of 22 groups of companies and around 125 sawmills in a total of 60 groups/companies, as well as a number of companies that have close ties with the production of pulp, paper and wood products.

Key statistical data on the forest industries are published annually in “The Swedish Forest Industries - Facts and figures”. Some production, energy use and emission data per individual mill are also published online in the Environmental database (Swedish Forest Industries 2015c). A quarterly update on the status and development of the forest industries is also published on the website (Swedish Forest Industries 2015d).

2.1.3. Trä- och möbelföretagen, TMF

Trä- och Möbelföretagen (TMF) is the national trade and employers’ association of the wood processing and furniture industry in Sweden and represents approximately 700 member companies who jointly have around 30 000 employees. The brief publication “TMF i siffror” (TMF in figures) appears twice a year, and also other statistics on the associated industries are available on the web site (TMF 2015a).

2.1.4. SDC

SDC is the forest industry's IT company. It handles the flow of information between forest and industry regarding product information, stock movements and measuring for timber, transport and biomass fuel transactions. The main areas of focus of SDC services and systems are: Wood procurement, harvesting, transportation, wood measurement and industrial consumption. Data on the production and feedstock consumption of the forest industry is published annually (SDC 2015).

2.1.5. Swedish energy agency

The Swedish Energy Agency is subordinate to the Ministry of the Environment and Energy. It is working with the promotion of energy efficiency measures and investments in renewable energy technologies. The energy agency publishes annual energy balances, biofuel markets overview and forest and peat fuel prices, among other energy-related statistics, available through their web site (Swedish Energy Agency 2015).

2.1.6. Forestry research institute of Sweden

The Forestry Research Institute of Sweden is a research body for the Swedish forestry sector, and is financed jointly by the government and the members of the Institute. The forestry research institute performs annual surveys of costs in forestry, in cooperation with the Swedish forest agency. The survey results are available on the web site (Forestry Research Institute 2015) along with other forest-related research results.

2.1.7. Statistics Sweden

Statistics Sweden is an administrative agency with the main task to supply customers with statistics for decision making, debate and research. Besides producing and communicating statistical data, Statistics Sweden is tasked with supporting and coordinating the Swedish system for official statistics. Some of the statistics relevant for this report are trade statistics and national input-output tables. The data are available as reports or through the on-line statistical database (Statistics Sweden 2015a).

2.1.8. Swedish petroleum and biofuels institute

The Swedish Petroleum and Biofuels Institute (SPBI) is an industry organization for fuel companies in Sweden. SPBI publishes certain statistical data, such as historical prices for key petroleum products and transportation fuels (SPBI 2015).

2.2. STAKEHOLDER SURVEY

A survey was sent to representatives from forest companies and forest owners associations, in which they were asked to comment on price and cost data compiled from the literature, in order to check the validity of the values. The questionnaire to the representatives is showed in Annex 1. However, out of nine persons contacted, only two replied. In addition to the survey, a number of persons with insights into the forest-based economy were contacted and asked to contribute information in an interview. The contacted persons are listed in Annex 2.

2.3. VALUE FLOW DIAGRAMS

The results of the value flow analysis are shown in tables and illustrated with Sankey diagrams. A Sankey diagram is a graphical illustration of flows, where each flow is represented by a line and the width of the line reflects the magnitude of the flow. Figure 8 shows an example for forestry, harvest and delivery of logs to the side of a road where they can be picked up by a truck. We have opted to show where the money comes from and where it goes, i.e. the direction of the value flow is opposite to the physical flow (of wood, in this example). In Figure 8, “value at roadside” is the price paid by the industry for logs delivered to the roadside. Part of that value is spent on costs for harvesting the wood and forwarding it to the roadside and part of it is the net harvest income to the forest owner. This income then also has to cover costs for other forestry related activities, such as soil preparation and planting of new trees, forest road construction and maintenance etc.

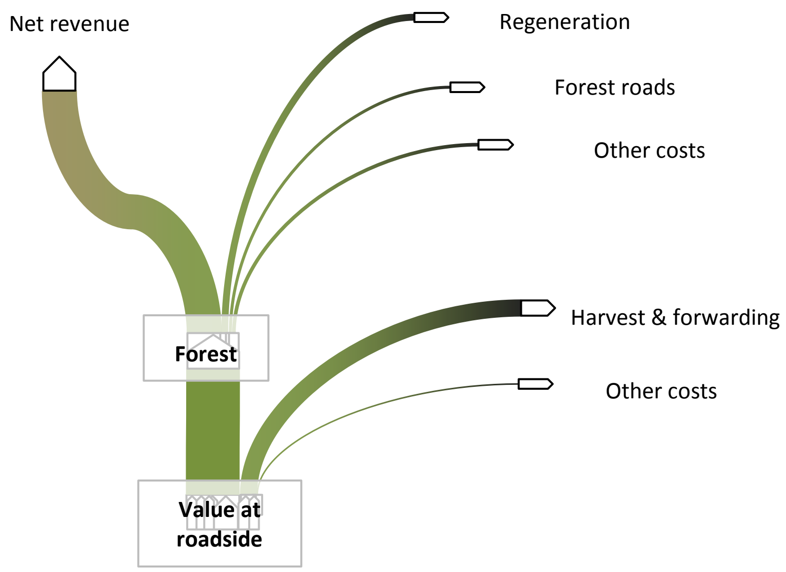


Figure 8. Value flow diagram example.

2.4. DETAILED REVIEW OF SELECTED VALUE CHAINS

Some more detailed data on production, market prices and value chains were compiled for selected products (softwood kraft pulp, dissolving cellulose pulp and ethanol) through interviews and collection of more detailed statistics.

2.5. DELIMITATIONS

In general, the study is not complete in the sense that it does not include all costs and revenues, but rather focuses on the values of the main forest products flows. For example, it includes the value of paper produced by the paper industry and the cost that the industry has for wood feedstock while costs for other inputs, such as pulping chemicals and filler materials are not included, nor are labor costs and capital costs. The studied flows may contain significant amounts of non-wood materials, for example, paper products often contain varying levels of mineral fillers and coatings. This study does not attempt to provide a full account of the cost and income structure of the studied sectors.

The sectors included are the forestry (i.e. the wood production) sector, the sawmilling industry, the pulp and paper industry, the pellets industry and the wood-based panels industry. Further use and refining of the wood in sectors such as construction, furniture manufacture, news media and print industry, packaging industry etc., was not covered in the study. The information collected for feedstock supply is more complete as it covers the most relevant forestry costs. Also, a complete picture of the forest-based industry is given on an aggregated level by using input-output data from the Swedish national accounts.

3. RESULTS

Figure 9 gives an overview of the economic flows to and from key sectors of the forest-based economy in Sweden in 2009, based on the symmetric input-output table from the national economic statistics[1] (Statistics Sweden, 2014). Goods and services generated in the economy respresent economic values. In general, these can either be exported, consumed domestically or remain as capital assets. Hence, the values generated, which drive the system, are divided in three groups: 1a) Final domestic consumption, i.e. what consumers spend on products and services to satisfy the needs and wants, 1b) exports, i.e. the income from goods that are exported for use or further refinement outside the Swedish border, and 1c) gross capital formation, i.e., domestic values generated in the form of capital assets (in contrast to goods and services for consumption), such as constructed buildings. On the other end of the diagram (2), the value flowing through the economy ends up in two main categories: 2a) imports, where money leaves the system as compensation for imported goods and 2b) an aggregated class composed of added value such as compensation to employees, operating surplus and taxes paid to society. The values generated also have to compensate for the consumption of fixed capital, which is included in 2b. For example, in the economic accounts, the income generated by selling wood from the forest is partly balanced by the loss in the forest capital stock (on the other hand, forestry also generates fixed capital by growing some 4% each year, also illustrated at the other end of the diagram). Taxes are shown as a net value of paid taxes less received subsidies.

The flows in the input-output tables are defined by products and services and aggregated into groups of related products and services, roughly reflecting different sectors of the economy. All net input and output flows to and from selected sectors were included in the diagram: (3) The primary production of wood in forestry and related services; (4) the primary wood processing industry divided into 4a) wood and products of wood, including for example the production of sawn wood products and 4b) paper and paper products, including the products of the pulp and paper sector; and (5) important downstream users of wood and paper products: 5a) construction and construction works, 5b) furniture and other manufactured products and 5c) printing, recording and publishing services. In addition, the net flows between these sectors and other parts of the economy (6) were included and grouped into: 6a) Energy, including electricity, gas, steam, air conditioning, coke and refined petroleum products; 6b) Transport services; 6c) Chemicals; 6d) other products; and 6e) other services.

There may be significant internal flows within each sector, and large flows both to and from one sector to another. The diagram, however, only shows net flows, except for the case of international trade, where both export and input flows are shown. Net flows with a magnitude smaller than 1000 MSEK are not shown.

[1] For a more in-depth description of the national accounts and definitions of the terminology, refer to, for example, Statistics Sweden (2009)

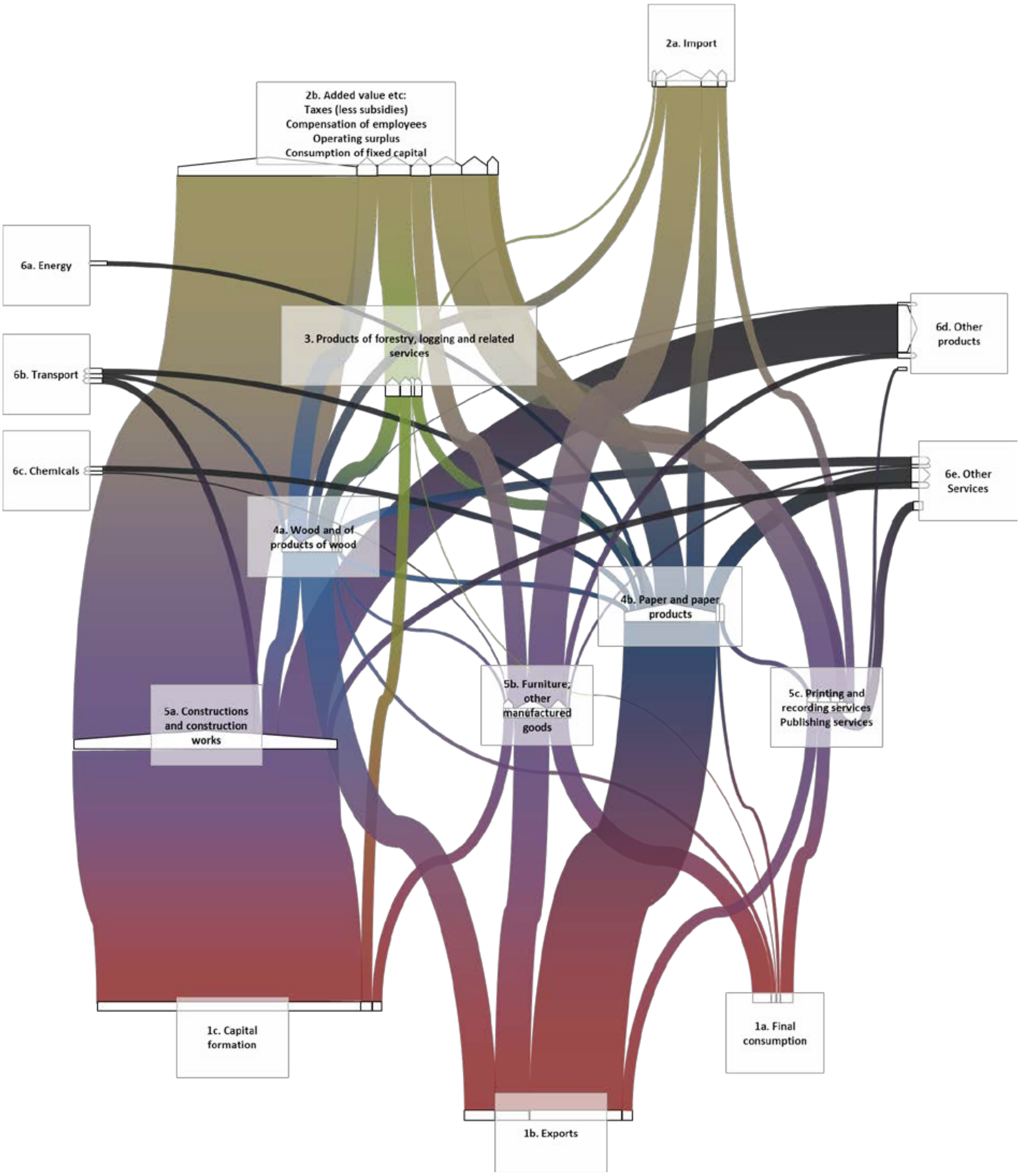


Figure 9. Overview of value flows based on input-output tables in the Swedish national accounts.

The diagram is dominated by the large capital formation in construction and construction works. The construction sector also generates a large flow to added value and consumption of fixed capital, out of which compensation to employees accounted for 60% and capital consumption for 10%. Large flows also go to wood products and other products; in total about 63000 MSEK out of which 27% to wood products.

Both the wood products and, especially, the paper products, have their main economic inflow from exports, and are also large net exporters since the import is comparatively small. The main net economic inflows to forestry came from wood products industry (14000 MSEK), from pulp and paper industry (9000 MSEK) and from capital formation (11000 MSEK). Compared to the production of wood products, the production of paper products have a more diversified cost structure, and the economic flow to the forestry sector is relatively small in comparison to the total value flow from the sector. Note that imports here refer to import of paper and paper products and not to import of feedstock. The import of wood to sawmills and pulp mills is represented by the flow between “import” and “Products of forestry etc.”. The small but still significant flow from paper and paper products to wood and wood products is most likely related to the flow of sawmill by-products to pulp mills.

The value flows to the forest industry sectors from the sectors of furniture and other manufactured goods and printing, recording and publishing services are small compared to the total turnover of these two sectors.

3.1. FOREST FEEDSTOCK PRODUCTION AND SUPPLY

Forest feedstock supply is fairly well described in the statistics, in terms of harvested and used volumes. Pricing is, however, complex and markets are to a large extent regional. Forest owner associations and forest companies publish pricelists, but the prices are subject to various adjustments and may not represent the actual amount paid to the forest owner. The price is typically given as price in SEK per solid m^3 excluding bark (m^3sub) delivered at roadside. In addition to the roadside price, the procurement cost for the industry may include for example transport costs, costs for measurement of wood, provisions and administrative costs.

Costs for forest management and for harvesting and forwarding of the wood from the harvested area to the roadside is well studied by for example Athanassiadis et al. (2010), Bergström & DiFulvio (2014) and Lundmark et al. (2015), but the costs are typically very site-specific. The most relevant price information found was survey results published by Skogforsk. The intention of the Skogforsk survey is to capture the actual costs involved in wood feedstock supply, and it is repeated annually. Survey results are published for roundwood supply and for forest fuel supply (see e.g. Brunberg 2010a,b).

3.1.1. Roundwood

The value of the produced roundwood has been calculated by multiplication of the amounts produced by estimated prices. The roundwood supply from the forest was calculated as the use of roundwood feedstock minus net supply from international trade and stock changes (Table 1). The estimated supply from forest was compared to aggregated values for production in fellings reported by the Swedish Forest Agency (2015) and showed good agreement. Costs for forest management, harvest and forwarding of harvested logs to roadside are given in Table 2. The total 2009 costs for regeneration, forest roads and other costs not directly related to harvest operations have been divided by the amount of roundwood delivered in 2009. The procurement cost of the industry is shown in Table 3. The price paid at roadside is based on wood bought through cutting commissions [2] and buying of standing forest [3]. Where the forest owner is also the user of the wood, the price at roadside may not be relevant. However, in this report, we apply it generally to calculate

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[2] The wood is measured and valued by the industry and payment is due at the current price list. Deductions for harvesting and forwarding costs are made

[3] The price for the standing volume is set before the area is harvested. The buyer can harvest the wood within 2 years.

the gross value of the wood delivered to roadside. The net value to the forest owner is calculated as the gross value minus costs according to Table 3. The actual distribution of the values between forest owner, forest industry and forestry service providers may vary depending on their relation and the applied business model. The value flows are illustrated in Figure 10.

Table 1. Roundwood use and supply in 2009.

[1000 m^3sub]	**Sawlogs**			**Pulpwood**		
	Pine	Spruce	Other	Pine	Spruce	Other
Roundwood use[a]	**13823**	**19394**	**212**	**12104**	**15542**	**6503**
Sawmills	13823	19394	212			
Pulp mills				12045	15134	6422
Wood-based panels industry[h]				59	408	81
Net supply from stocks[b]	**4507**[e]		**-355**[g]	**1477**[e]	**174**	**794**
Net supply from trade[c]	**-339**		**448**	**3380**		
Import	373[e]		456	*3795*[i]		
Export	-712		-8	-415		
Net supply from stocks and import	**2084**[f]	**2084**[f]	**93**	**2429**[f]	**2429**[f]	**794**
Net supply from forest[d]	**11798**	**17718**	**200**[g]	**9617**	**12706**	**5628**

Sources:
a) SDC (2014).
b), c) Swedish Forest Agency (2014).
d) Calculated as difference between roundwood use and net supply from stocks and imports.
e) “Coniferous”, may include both pine and spruce
f) Assume equal amounts of pine and spruce
g) No data for stock changes. Supply from forest based on Swedish Forest Agency (2014) and the stock changes adjusted to balance supply and demand.
h) Assumed to be pulpwood only.

Table 2. Costs for forest management and roundwood supply to roadside, per delivered solid m3sub in 2009.

	Northern Sweden	**Southern Sweden**	**Sweden average**[a]	**Total 2009**[b]
	SEK/m^3sub	SEK/m^3sub	SEK/m^3sub	MSEK
Forest management etc.	**82**	**77**	**79**	**5061**
Regeneration	45	37	40	2568
Forest roads	17	18	18	1130
Other	20	22	21	1363
Harvest	**114**	**107**	**109**	**7011**
Harvest & Forwarding	105	98	100	6441
Other	9	9	9	570

Sources: Brunberg (2010a) except for
a) Calculated as a weighted average assuming 38% of harvested volume in northern Sweden and 62% in southern, based on average gross harvested volumes in 2011-2013 (Swedish Forest Agency, 2014)
b) Calculated by multiplication of Swedish average cost by harvested volumes according to table 1

Table 3. Roundwood procurement costs for the industry in 2009. Weighted averages for Sweden with values for northern/southern Sweden given in brackets.

[**SEK/m3sub**]	**Sawlogs**			**Pulpwood**			**Other**[c]	**Total**[b]
	Pine	Spruce	Other[a]	Pine	Spruce	Other		MSEK
Price at roadside	514 (523/508)	508 (411/568)	511	316 (320/313)	329 (323/332)	327 (317/333)	170	25147
Transport	77 (73/80)	69 (63/73)	181	81 (74/86)	74 (68/78)	89 (82/93)	81	4895
Other costs	5	5	5	4	4	4	5	291
Totalt	**596 (601/593)**	**583 (479/646)**	**589**	**401 (398/403)**	**407 (395/414)**	**420 (403/430)**	**256**	**30334**

Sources: Brunberg (2010a) except for:
a) No data available. Assumed as the average of spruce and pine costs.
b) Calculated by multiplication of Swedish average cost by harvested volumes according to table 1
c) Fuelwood etc. The price at roadside was estimated from Swedish Forest Agency (2015). Transport and other costs were set to an average of corresponding costs for other assortments.

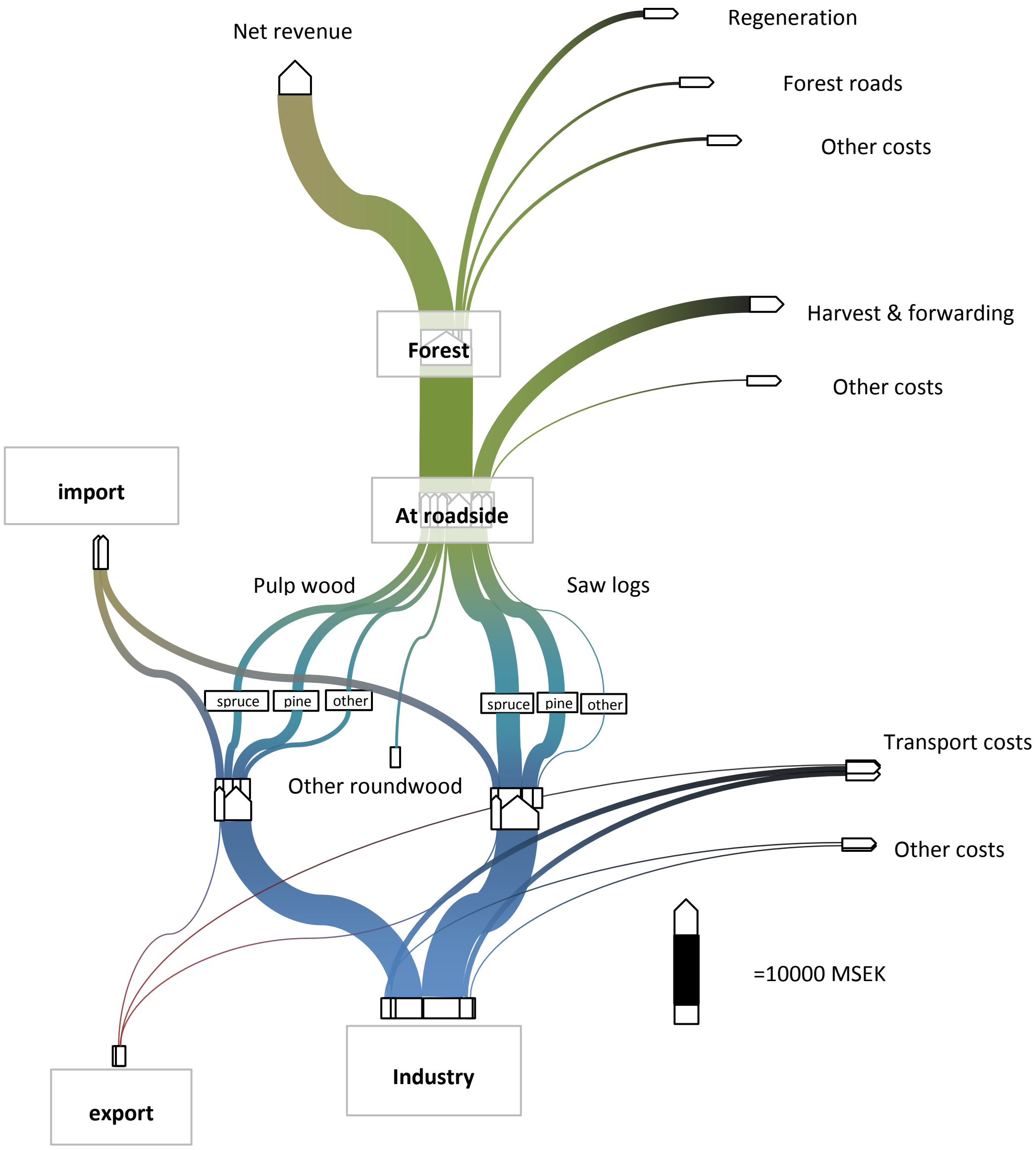


Figure 10. Monetary value flows from the industry back through the roundwood supply chain.

3.1.2. Forest fuel

Costs related to the supply of four forest fuel assortments are given in Table 4. The forest fuel supply is dominated by logging residues and energy wood. Energy wood was assumed to be included in the "other roundwood" category (see previous section) and is not dealt with here. Hence, our focus in the following is on logging residues. Also data for stumps was calculated for comparison and since it was included in the 2009 physical flows compiled by Anderholt-Helgesson et al (2012).

Table 4. Costs related to the supply of comminuted forest fuel to the user, measured as SEK/m³l delivered.

	Logging residues	**Small trees**	**Energy wood**	**Stumps**
	SEK/m³l	SEK/m³l	SEK/m³l	SEK/m³l
Land-owner compensation	39	14	60	2
Harvest	0	41	14	43
Forwarding	33	26	19	25
Administration etc.	8	6	9	3
Subtotal at roadside	**80**	**87**	**102**	**73**
Comminution	44	31	16	40
Terminal costs	7	6	12	8
Transport	34	34	29	46
Administration etc.	7	6	8	6
Total free of user	**172**	**165**	**167**	**174**

Source: Brunberg (2010b)

Prices given by Brunberg (2010b) in SEK/m³l, after comminution by chipping or crushing, were converted to SEK/MWh, since forest fuel is today measured and traded mainly in energy units. Conversion factors are given in Table 5. The total supply cost amounted to 226 and 229 SEK /MWh, for logging residues and stumps, respectively. However, the average 2009 price reported for forest fuel by the Swedish Energy Agency (2015) was only 179 SEK/MWh (See also Table 13). The reasons for this discrepancy are not clear. The data are, however collected in different ways, and the Energy Agency data represents the actual costs for the fuel used during the past quarter which may not equal the actual market prices for the fuel assortments, since long fuel delivery agreements may cause the cost to differ from the price level on the market (Swedish Energy Agency and Statistics Sweden 2015), Table 6 shows the total values and costs related to logging residues and stumps at a forest fuel price of 230 SEK/MWh, while the corresponding values at a price of 180 SEK/MWh are given in Table 7. The total supply of forest fuel from logging residues and stumps were estimated to 9900 GWh and 750 GWh, respectively (Anderholt-Helgesson, Häggström, Leffler, 2012).

Table 5. Conversion factors. Equivalents to 1 m³l.

[/m³l]	**Logging residues**	**Small trees**	**Energy wood**	**Stumps**
MWh	0.76	0.76	1.22	0.76
m³s	0.37	0.37	0.50	0.37
t (wet)	0.32	0.32	0.30	0.31
tDM	0.16	0.16	0.24	0.17

Source: Swedish Energy Agency (2014c) and own calculations

Table 6. Value and procurement costs for logging residues and stumps in 2009, at an assumed price of 230 SEK/MWh free of the user.

	Logging residues		Stumps	
From forest[a]	9900	GWh	750	GWh
Value free of user	**2277**	**MSEK**	**173**	**MSEK**
Costs from roadside to user	1198	MSEK	99	MSEK
Cost from harvest site to roadside	534	MSEK	70	MSEK
Net before land-owner compensation	**545**	**MSEK**	**4**	**MSEK**
Land owner compensation	508	MSEK	2	MSEK
Net	**36**	**MSEK**	**2**	**MSEK**

Sources: calculated based on data in Tables 4 & 5, and from
a) Anderholt-Helgesson, Häggström, Leffler (2012)

Table 7. Value and procurement costs for logging residues and stumps in 2009, at an assumed price of 180 SEK/MWh free of the user.

	Logging residues		Stumps	
From forest	9900[a]	GWh	750[a]	GWh
Value free of user	**1767**	**MSEK**	**134**	**MSEK**
Costs from roadside to user	1198	MSEK	99	MSEK
Cost from harvest site to roadside	534	MSEK	70	MSEK
Net before land-owner compensation	**35**	**MSEK**	**-35**	**MSEK**
Land owner compensation	508	MSEK	2	MSEK
Net	**-473**	**MSEK**	**-37**	**MSEK**

Sources: calculated based on data in Tables 4 and 5, and from
a) Anderholt-Helgesson, Häggström, Leffler (2012)

The cost data in Brunberg (2010b) was not reported separately for northern and southern Sweden. It should, however, be noted that forest fuel is extracted to a larger extent in southern Sweden, whereas there is presently little to no demand for logging residues in northern Sweden since there is a surplus of forest industry by-products available. For example, one interviewed person from the northern part of Sweden estimated present by-product prices in the range of 130-170 SEK /MWh, and the logging residue price to about 175 SEK /MWh. At the same time, logging residues were considered as a more difficult fuel to handle than industrial by-products. There may, however, be regional variation. Some buyers may be bound by long-term contracts, and there may also be some who continue to buy small amounts of logging residues in order to maintain the infrastructure, in case of a larger need in the future.

Overall, the value of the forest fuel flow (Figure 11) is small compared to the value of the roundwood flow, and a smaller share of the value of the fuel delivered to the industry gate reaches the land owner, due to relatively high costs for extraction, transport and handling. The roundwood and forest fuel supply chains are, however, not directly comparable. For example, the forest fuel chain includes comminution of the feedstock, whereas the roundwood is delivered as logs.

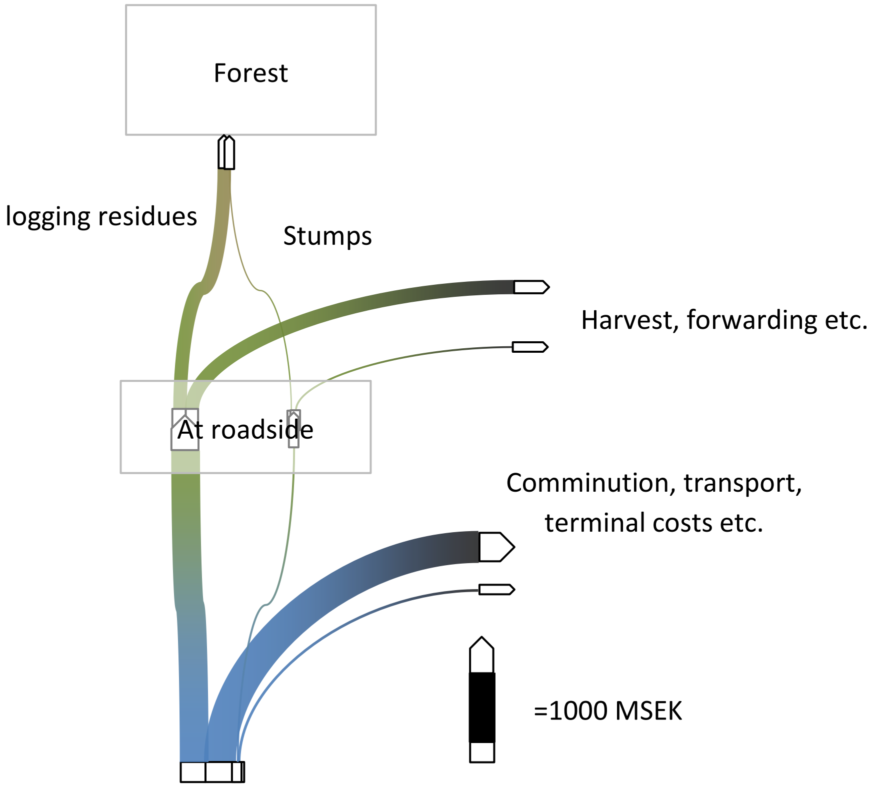


Figure 11. Monetary value flows from forest fuels users back through the supply chain. Note that the scale is ten times larger than in the other flow diagrams in the report.

3.2. SAWMILLS AND WOOD-BASED PANELS INDUSTRY

Data on production, import and export of sawn and planed wood products and wood-based panels are shown in Table 8 and illustrated in Figure 12. A large share of the production is exported, and we value the product flows based on their export price which is calculated as exported volume in m^3 of sawn wood (m^3sw) divided by the total export value in SEK. The production and export is heavily dominated by sawn and planed products of spruce and pine. The Swedish wood-based panels industry is small in comparison to the sawmill industry, and has been in decline over the past few years (TMF 2015b).

Table 8. Production and trade of sawn and planed wood and wood-based panels in 2009.

	Specific value[a]	Total production	Import		Export	
		Volume	Value	Volume	Value	Volume
	SEK/ m^3sw	1000 m^3sw	MSEK (CIF)	1000 m^3sw	MSEK (FOB)	1000 m^3sw
Sawn and planed wood products	**1889**	**16 222**	**1 026**[c]	**356**[c]	**23 175**	**12 271**
Coniferous	1886	16 116	c	c	23 104	12 252
Non-coniferous	3845	106	c	c	72	19
Wood-based panels	**5462**	**780**	**3040**	**937**	**1376**	**252**
Particle board	3533	587	1184	480	247	70
Fiber board	7117	193[b]	1127	302	954	134
Plywood	3654	b	729	155	175	48

CIF: Including cost, insurance and fright. FOB: Free on board
Source: Swedish Forest Agency (2014a, b)
a) Calculated as the export price (export value divided by export volume)
b) Production volumes of fiber board and plywood is aggregated
c) Import of coniferous and non-coniferous sawn wood products is aggregated

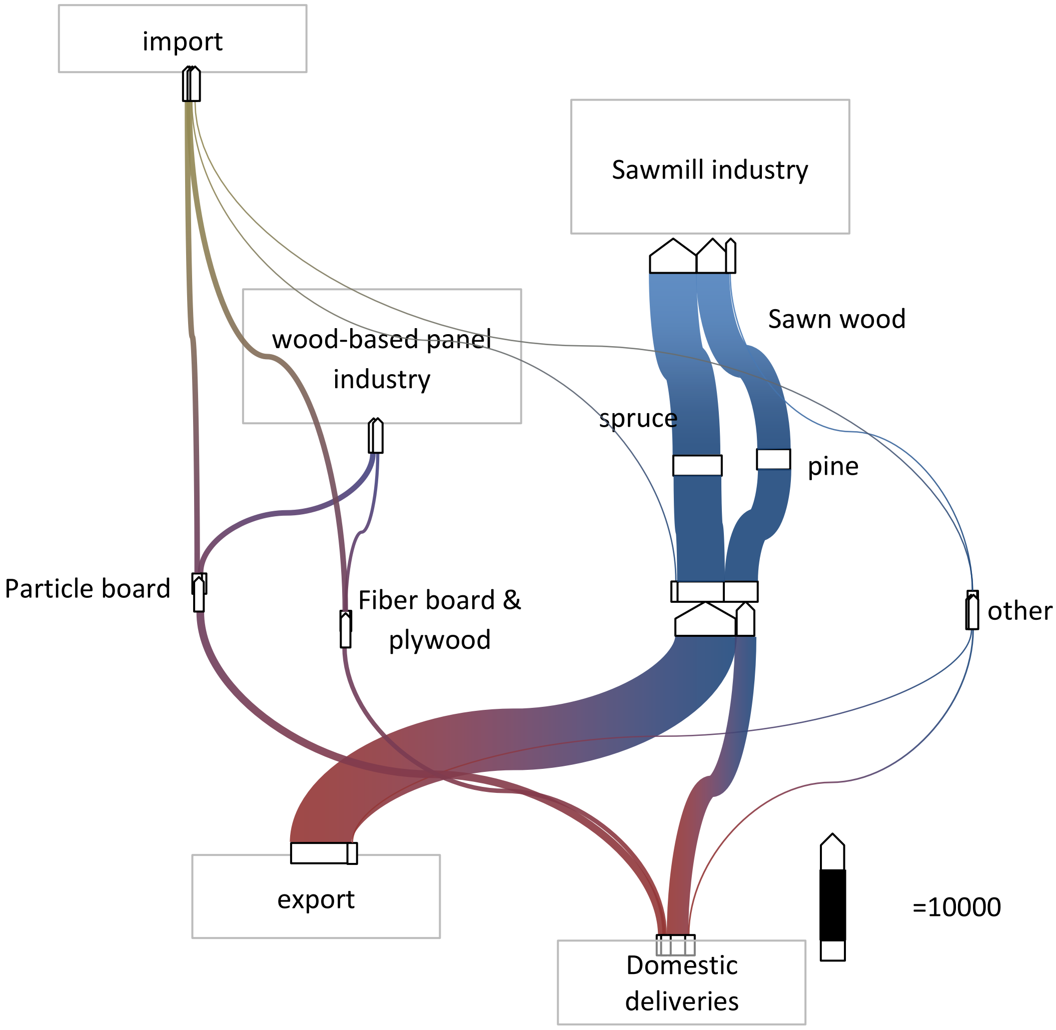


Figure 12. Monetary value flows from the buyers of sawn and planed wood and wood-based panels back through the supply chain.

3.3. PULP AND PAPER INDUSTRY

Data on production, import and export of pulp in 2009 is shown in Table 10 and corresponding information for paper production is given in Table 11. The pulp production is dominated by a few, large companies and the figures for domestic production published by the Forest Industry Federation are on an aggregated level, since further disaggregation is not possible due to confidentiality issues. The trade statistics published by Statistics Sweden are more detailed.

Pulp is either used directly in a paper mill that is integrated with the pulp mill, or dried and sold as market pulp. Mechanical pulp is predominately used for integrated paper-making, while close to half of the produced chemical pulp is sold as market pulp. Bleach softwood sulphate pulp accounted for about 2600 kt of the market pulp and 3800 kt of the total production.

Pulp and paper are typically international commodities and hence priced on the international market. The market price is volatile. The price trend for chemical pulp is positive, and prices are presently higher than in 2008, before the financial crisis (Figure 13). Graphical papers, however, have not regained the pre-crisis price levels (Table 9). The average export price, which was used here as a proxy to product value, represents an average over the year and is therefore relevant for quantifying the value stream for a given year. The export price is also consistent with the Swedish national border as the system boundary of the study. The export price rather that the import price was used since the volume of the export is far larger than the volume of the import for most of the products in the study.

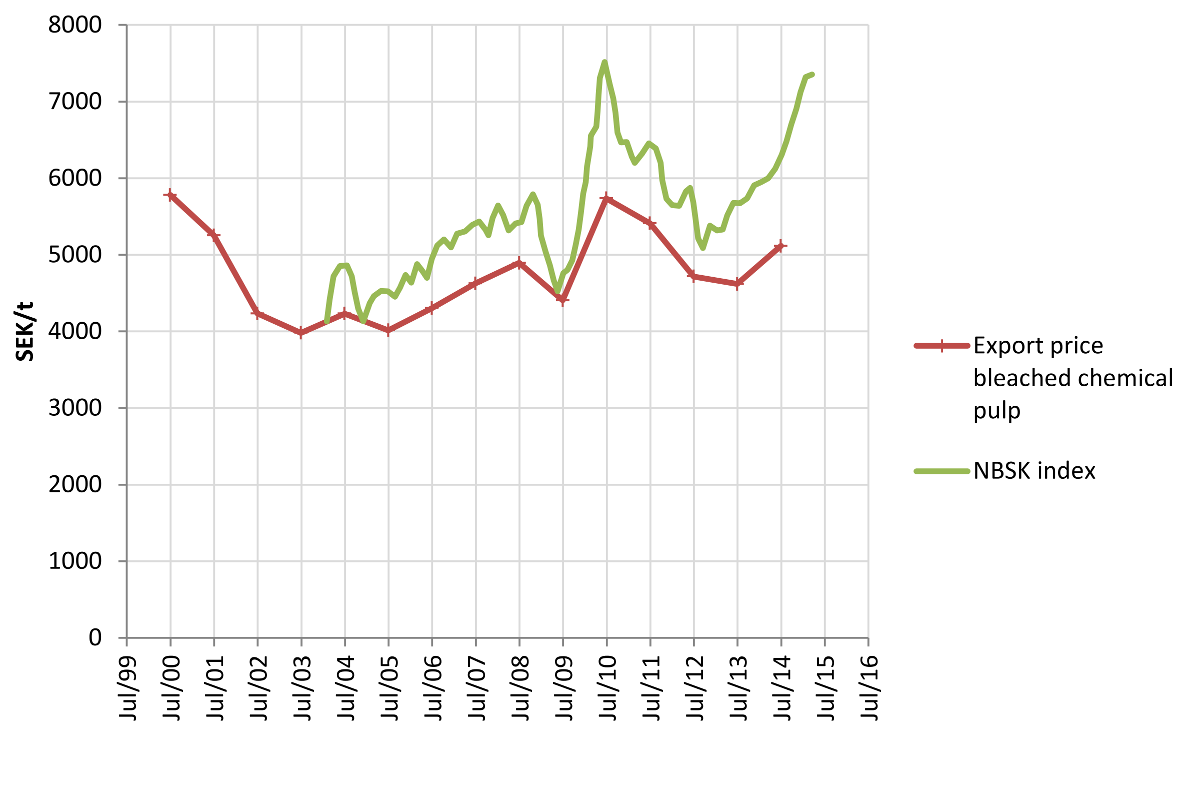


Figure 13. Northern bleached softwood kraft (NBSK) price index for Western Europe and annual average Swedish export price for bleached sulphate and soda pulp (Swedish Forest Industries Federation, 2015, Statistics Sweden, 2015b).

Table 9. Approximate market prices for newsprint, super-calendered (SC) and light-weight coated (LWC) graphical papers.

[€/t]	2008	Spring 2015
News, 45 g	530	400
SC, rotogravure, 56 g	600	500
LWC, offset, 60 g	670	590

Source: Information from industry.

Pulp for integrated papermaking is not put on a market, and hence does not have a market price. It is therefore difficult to assign a value to it. To a mill wanting to sell some of its integrated pulp production, the value of the pulp would likely be lower than the market price of market pulp, since the required drying of the pulp would incur significant costs. To a mill with a pulp deficit, however, the value of an additional unit of integrated pulp produced could be higher than the market pulp price, since it would be readily available and some processing required for market pulp may be avoided. As a very rough approximation, we valued internal pulp as market pulp. Especially for mechanical pulp, where only a very small share is sold as market pulp, this internal price may not be relevant. The value flows are illustrated in Figure 14.

Table 10. Production, import and export of pulp in 2009

	Specific value[a]	Total production[b]	Thereof market pulp[b]	Import[c]		Export[d]	
	SEK/t	kt	kt	MSEK (CIF)	kt	MSEK (FOB)	kt
Chemical pulp	**4521**	**7 874**	**3 395**	1263	323	**13914**	**3078**
Sulphate pulp	**4400**	**n.d.**	**n.d.**	**1114**	**288**	**12526**	**2847**
Unbleached	4103	n.d.	n.d.	0.57	6.1	324	79
Bleached	4408	n.d.	n.d.	1113	282	12201	2768
Other chemical pulp	**6018**	**n.d.**	**n.d.**	**149**	**35**	**1388**	**231**
Sulphite pulp	4076	n.d.	n.d.	10	20	57	14
Dissolving pulp	6144	n.d.	n.d.	139	15	1331[c]	217[c]
Semi-chemical pulp	**3364**	**279**	**0**	**142**	**42**	**626**	**186**
Mechanical pulp	**4271**	**3 322**	**344**	66	20	**329**	**77**
Recycled paper	**1084**	**n.d.**	**n.d.**	**764[d]**	**895[d]**	**347**	**320**

n.d.: No data
Sources:
a) Calculated as the export price (export value divided by export volume)
b) Swedish Forest Industries Federation (2012a)
c) Statistics Sweden, statistical databases on international trade (accessed June 2015)
d) Swedish Forest Agency (2014a, b)

Table 11. Production and trade of paper, paperboard and other products made from pulp in 2009.

	Specific value[a]	Total production[b]	Import[c]		Export[c]	
	SEK/t	kt	MSEK (CIF)	kt	MSEK (FOB)	kt
Newsprint	**4899**	**2 151**	**227**	**35**	**8 055**	**1 644**
Mechanical printing paper	**6538**	**1 787**	**1 815**	**252**	**12 766**	**1 952**
Coated	6785	n.d.	573	77	3 908	576
Uncoated	6435	n.d.	1 241	174	8 858	1 377
Woodfree printing paper	**7822**	**1 273**	**957**	**99**	**8 634**	**1 104**
Coated	8385	n.d.	596	66	2 342	279
Uncoated	7631	n.d.	361	33	6 292	824
Tissue paper	**16139**	**338**	**1 180**	**81**	**4 288**	**266**
Wrapping paper	**7039**	**999**	**102**	**12**	**5 851**	**831**
Paperboard for packaging	**8803**	**2 376**	**942**	**67**	**17 758**	**2 017**
Corrugated material	**4536**	**1 892**	**970**	**248**	**8 496**	**1 873**
Boxes	**19830**	**n.d.**	**1 129**	**85**	**2 104**	**106**
From corrugated board	15502	n.d.	589	56	557	36
From other paper/board	22046	n.d.	540	29	1 547	70
Other	**16490**	**117**	**7 357**	**421**	**9 528**	**578**
Diapers etc	29969	n.d.	1 570	46	2 974	99
Other	13696	n.d.	5 787	375	6 554	479
Total	**7471**	**10 933**	**14 680**	**1 300**	**77 480**	**10 371**

n.d.: No data
Sources:
a) Calculated as the export price (export value divided by export volume)
b) Swedish Forest Industries Federation (2012a)
c) Statistics Sweden, statistical databases on international trade (accessed June 2015)

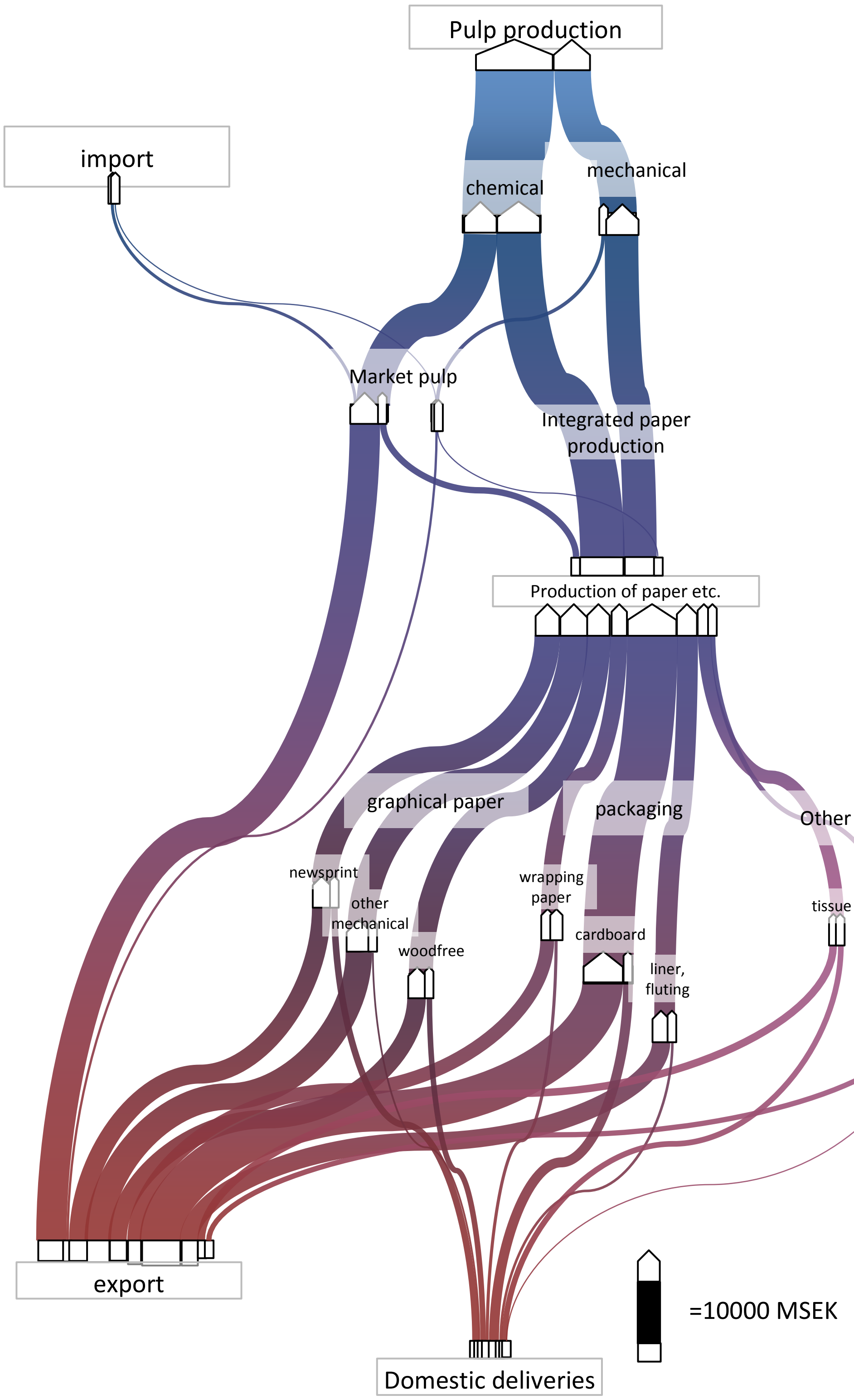


Figure 14. Monetary value flows from the buyers of pulp and paper products back through the value chain.

3.4. FOREST INDUSTRY BY-PRODUCTS

The forest industry produces significant amounts of by-products. These are to a large extent utilized within the industry (Table 12). Sawmills produce bark, sawdust and wood chips, either fresh that can be used for pulping or dry, which is typically used for energy recovery or for wood-based board production. Bark and sawdust are used for energy or – in the case of sawdust – for wood-based board production. Sawdust may also be pressed into pellets or briquettes, sometimes called refined wood fuels.

Table 12. Production and use of forest-industry by-products in 2009, MtDM.

[MtDM]	pulp chips	Energy chips	Sawdust, cutter shavings etc.	Bark	Spent pulping liquors	Total
Production	**4.2**	**0.6**	**2.0**	**2.9**	**7.6**	**17.2**
Sawmills	3.8	0.6	2.0	1.2	-	**7.5**
Pulp mills	-	-	-	1.7	7.6	**9.3**
Import	0.4	-	-	-	-	**0.4**
Use	**4.2**	**0.5**	**2.0**	**2.9**	**7.6**	**17.2**
Sawmills	-	0.2	0.2	0.5	-	**0.9**
Wood-based panels industry	-	0.1	0.3	0.0	-	**0.4**
Pulp mills	4.2	-	0.0	1.7	7.6	**13.6**
Pellets production	-	-	1.4	-	-	**1.4**
District heating	-	0.2	-	0.6	-	**0.8**
Other	-	0.02	0.2	0.02	-	**0.2**

Source: Anderholt-Helgesson, Häggström, Leffler (2012)

Fuel prices for refined wood fuels and for solid industry byproducts are reported by the Swedish Energy Agency (Table 13).

Table 13. Wood fuel prices, SEK/MWh free of the user

[SEK/MWh]	**Refined wood fuels**	**Wood chips (logging residues etc.)**		**By-products**	
	District heating	Industry	District heating	Industry	District heating
Year					
2009	298	176	181	172	170
2010	300	200	197	188	179
2011	300	199	214	197	184
2012	292	189	209	188	185
2013	296	197	199	177	179

Source: Swedish Energy Agency (2015)

The prices of Table 13 in SEK/MWh were converted to SEK/tDM by assuming an energy density of 4.7 MWh/tDM for all solid by-products. For consistent pricing, we chose to apply the industrial by-products price, 172 SEK/MWh, to all solid by-products, except for fresh chips for pulping. Pulping chips was assigned a value corresponding to a price of 400 SEK/m^3sub, based on the pulpwood cost of the industry. The largest by-product flow, however, is the spent pulp liquor produced in chemical pulping. The spent liquor consists of, mainly, water, dissolved lignin and pulping chemicals. Efficient recovery of the chemicals is essential for chemical pulping. Combustion of the liquors also supplies a large share of the energy needed in the pulp and paper industry. Hence, the liquor has a value both in terms of its energy value and in terms of the pulping chemicals that it contains. Here, we chose to value it by its energy value and set this value to 172 SEK/MWh, i.e. the industrial price for solid by-products (Table 13). The energy value of the spent liquors combusted in 2009 was 40.1 TWh (Swedish Energy Agency and Statistics Sweden, 2012) giving a total value of 6168 MSEK. The values of the by-product flows have been summarized in Table 14 and illustrated in Figure 15.

Table 14. Value of produced and used by-products in the forest industry in 2009, MSEK

[MSEK]	Wood chips, pulp	Wood chips, energy	Sawdust, cutter shavings etc.	Bark	Spent pulping liquors	Total
Production	**4081**	**469**	**1576**	**2319**	**6168**	**14614**
Sawmills	3700	469	1576	938		**6683**
Pulp mills				1382	6168	**7550**
Import	382					**382**
Use	**4090**	**424**	**1463**	**2340**	**6168**	**14485**
Sawmills		159	150	443		**753**
Wood-based panels industry		65	207	19		**290**
Pulp mills	4090		14	1382	6168	**11653**
Pellets production			1091			**1091**
District heating		186		482		**668**
Other		14	0	15		**29**

Source: Calculated based on table 12. See text for details.

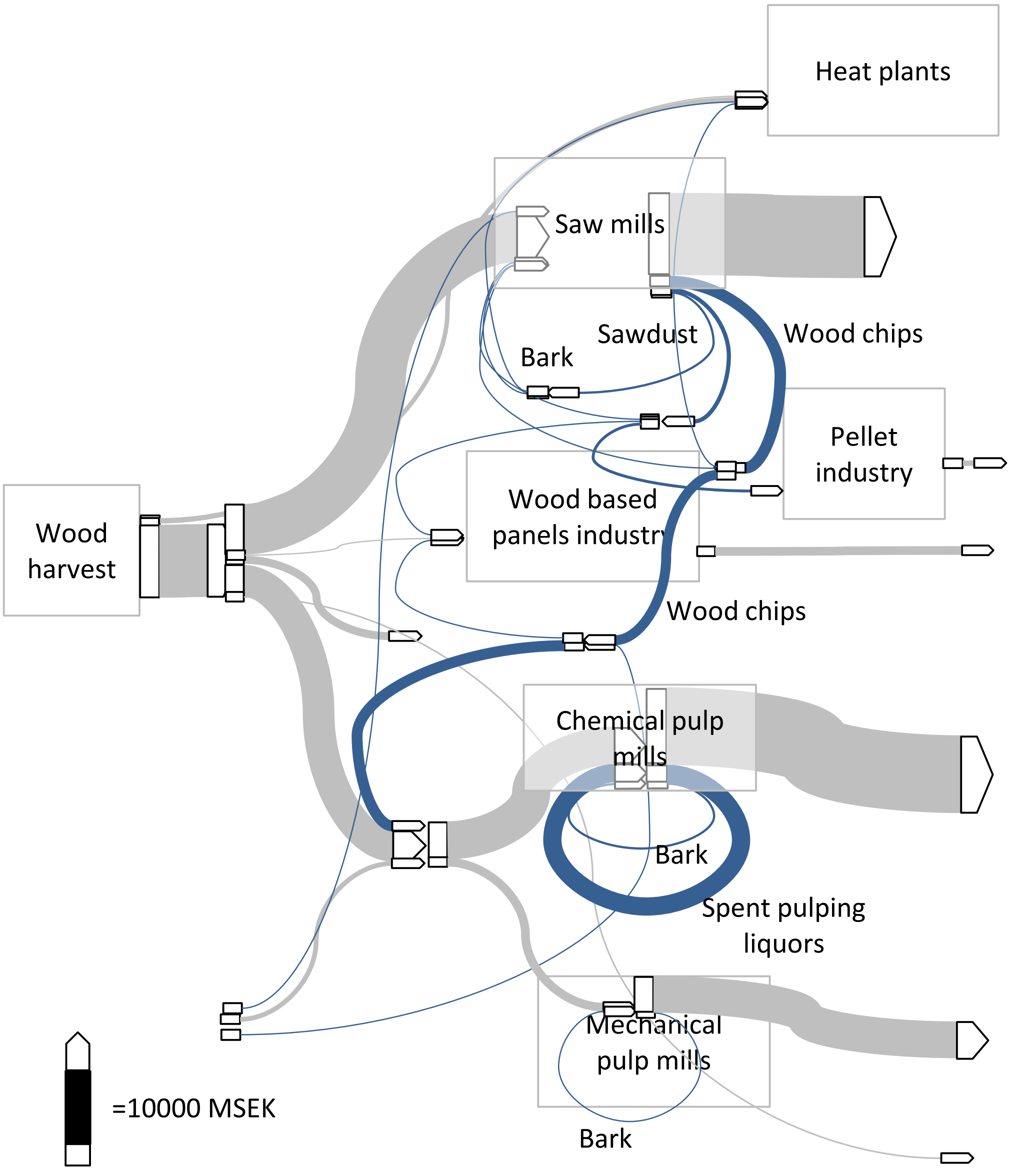


Figure 15. Estimated values of forest industry by-product flows.

3.5. SUMMARY OF VALUE FLOWS

Figure 16 combines the value flow diagrams of section 3.1-3.4 into a joint value flow diagram, which has been superimposed on the diagram based on the national input-output tables shown in Figure 9.

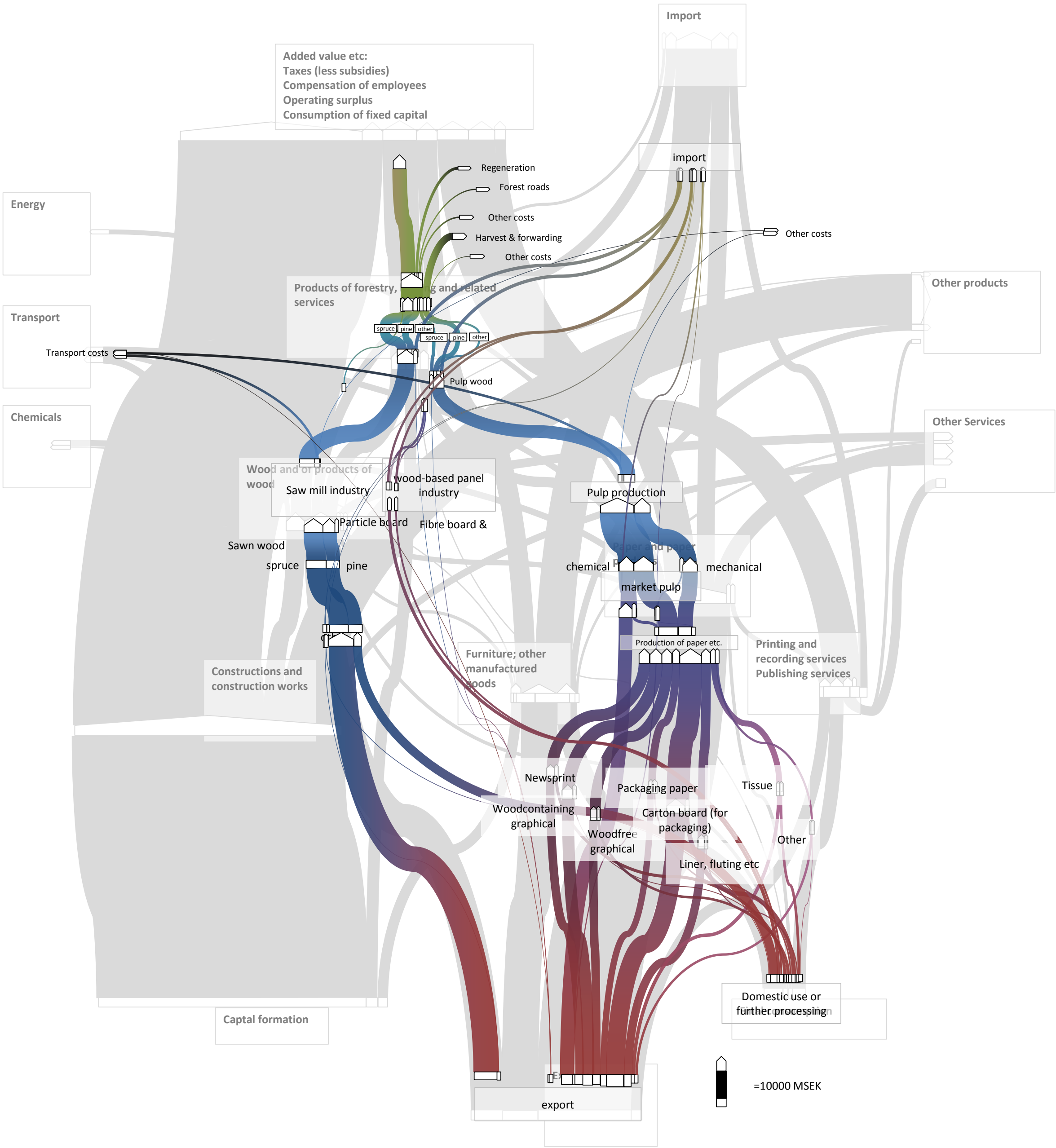


Figure 16. Combined value flows of the studied sectors.

4. COMPARISON OF SELECTED VALUE CHAINS

Whereas the previous sections have given an overview of aggregated value flows in the forest-based economy, the reality is far more complex and each individual production case is in practice more or less unique. Here, we describe in a bit more detail, but still in general terms, two variations of chemical pulping processes – sulphate pulping for production of bleached softwood kraft pulp and sulphite pulping for production of dissolving pulp. The downstream value chain from dissolving pulp to viscose textile products is also described. Next we describe a process for production of ethanol from wood. The processes were chosen because of their similarities, in that they are based on chemical or biochemical separation of the wood into its components, with the main product based on cellulose (dissolving pulp) or cellulose and hemicelluloses (ethanol and kraft pulp).

4.1. BLEACHED SOFTWOOD PULP VIA THE SULPHATE PROCESS

Sulphate pulping according to the kraft process is the dominating chemical pulping technology today. It uses mainly roundwood and sawmill wood chips as feedstock. Logs are debarked and chipped before they are fed to the cooking process. In the cooking process, the lignin is dissolved using chemicals and elevated temperatures. The fiber fraction, containing mainly cellulose and hemicellulose, is washed and bleached in a sequence of steps before it is dried and baled for shipping to customers. Alternatively, it can be fed to an integrated paper machine without prior drying. The spent cooking liquor containing dissolved lignin and pulping chemicals is called black liquor. It is passed through several evaporators in order to raise the dry matter concentration. The concentrated black liquor is combusted in the recovery boiler where the pulping chemicals are recovered and steam is generated for use in the processes. Part of the energy in the steam is typically used to produce electricity in a turbine and heat may also be exported to nearby industries or district heating networks.

Important side-streams that appear as by-products to the sulphate pulping process are (Staffas et al. 2015, STFI 2003):

- Bark, used for fuel internally or externally.
- Extractives: Tall oil and turpentine. Tall oil can be used internally for energy or sold externally. It can replace fuel oil, be upgraded to diesel- or gasoline-like motor fuel or be refined into various chemicals. Turpentine is as internal fuel or sold for use for example as a solvent.
- Methanol condensate. Mainly used as internal fuel, since it contains sulfur compounds that makes it difficult to handle. There is an ongoing project for upgrading the methanol for other uses.
- Various types of sludge, which are typically incinerated internally or landfilled.

The exact yields vary with the feedstock, the process design and the quality of the pulp that is produced. Table 15 gives typical values. Incineration of the black liquor will, in a modern mill, generate a surplus of heat and electricity which can be exported.

Table 15. Output from NBSK production, per tDM of wood (excluding bark) input.

	Production per tDM wood input	
Pulp	430	kgDM
Bark	110[a]	kgDM
Tall oil	15	kgDM
Terpenes	2	kgDM
MeOH condensate	4	kg
Fiber sludge	17	kgDM
Fiber loss at wood yard etc.	20	kgDM
Remainder[b]	513	kgDM

Source: Staffas et al. (2015), STFI (2003).
a) Calculated assuming only roundwood input and 11% bark content
b) Calculated as the difference between wood input and output products excluding bark. It refers mainly to lignin dissolved in the black liquor, which is combusted in the recovery boiler.

Northern bleached softwood kraft pulp (NBSK) is traded as an international commodity, and its market price is an important bench mark for several pulp and paper products. The fiber properties of NBSK make it useful as reinforcement pulp, providing strength, whereas hardwood pulps with shorter fibers are more suitable where printability is important.

4.2. DISSOLVING PULP VIA THE SULPHITE PROCESS

Similar to the sulphate pulping process, sulphite pulping uses chemicals to dissolve the wood into its components. The chemistry is, however, somewhat different and the products generated from the process differ from those of the sulphate pulping process. The process was earlier the dominating chemical produces for production of paper pulp, but has been outcompeted by the kraft process. It is, however, well suited for production of dissolving pulp. Here, the pulp product is almost pure cellulose, and the spent liquor thus contains both lignin and dissolved hemicellulose. The hemicellulose sugars can be fermented to ethanol which is separated and purified. The lignin is sulphonated in the process and termed lignosulphonate. It can be separated and dried for external sale or it can be combusted in a boiler for recovery of energy and chemicals. Table 16 gives the approximate annual wood consumption and product output of the Domsjö Fabriker dissolving pulp mill. The Domsjö mill also produces biogas through biological treatment of waste water, and carbon dioxide, which is recovered from the fermentation process. A pitch fraction containing extractive substances is also recovered.

Table 16. Key inputs and outputs of the Domsjö dissolving cellulose mill.

	Domsjö mill[a]		Per tDM wood[b]	
Input				
Wood	1.2	Mm^3sub	1000	kgDM
Electricity	240	GWh	484	kWh
Fuel	10	GWh	20	kWh
Output				
Pulp	195	kt	354	kgDM
Bark	n.d.		110[c]	kgDM
Lignosulphonate	80	kt	161	kg
Ethanol	15	kt	30	kg
Biogas	11	kt	22	kg
Pitch	6	kt	12	kg
CO_2	n.d.		29[d]	kg
Remainder			391[e]	kg

n.d.: No data
Sources:
a) Domsjö (2014)
b) Calculated assuming a wood density of 413 kgDM/m^3fub and 90% dry matter content of the pulp product.
c) Calculated assuming only roundwood input and 11% bark content
d) Calculated as the stoichiometric yield of CO_2 in conversion of sugar to ethanol. All of this may not be recovered.
e) Calculated as the difference between wood input and listed products, excluding bark.

The main application for dissolving pulp is in the production of viscose textile and nonwovens. It is also sold as specialty cellulose for use in various applications, such as thickeners, sausage casings and as microcrystalline cellulose in medicals. To produce textile, the pulp is chemically dissolved and then regenerated into a continuous fiber, which is normally cut into shorter fibers, a few centimeters of length – about the length of a cotton fiber. The cut fiber is called staple fiber. It is typically mixed with other fibers, such as cotton, and spun into a thread. The thread is weaved or knitted into a fabric which can be used, for example, for garment confection.

The Swedish dissolving pulp producer Domsjö Fabriker AB belongs to the Aditya Birla group, which is the world's number one producer of viscose staple fiber (Aditya Birla, 2015). Aditya Birla has production of dissolving pulp in India and Canada, besides Sweden, and viscose fiber production in India, Thailand, China and Indonesia. The annual production of viscose fiber is approximately 1 million tonne (Domsjö 2015).

The textile industry is predominately located in Asia, and the Chinese market price for staple fiber is an important benchmark. Figure 17 shows the price development of staple fiber in Asia. The fiber price is mainly set by the cotton price which varies with demand and cotton harvest yields. It is also under political influence. With increasing demand for viscose fiber, several kraft mills have been converted to produce dissolving grade cellulose. Some also have the ability to swing between kraft pulp production and dissolving pulp production, thereby linking the dissolving pulp market to the kraft pulp market. Whereas the kraft and dissolving pulp prices may vary considerably relative each other, it is believed that, over time, the dissolving pulp price should be about 20% higher than the kraft pulp price, reflecting the higher production costs for the dissolving pulp, which is a result of lower pulp yield, higher chemical dosage and longer cooking times required for dissolving pulp as compared to kraft pulp (industry information, personal communication).

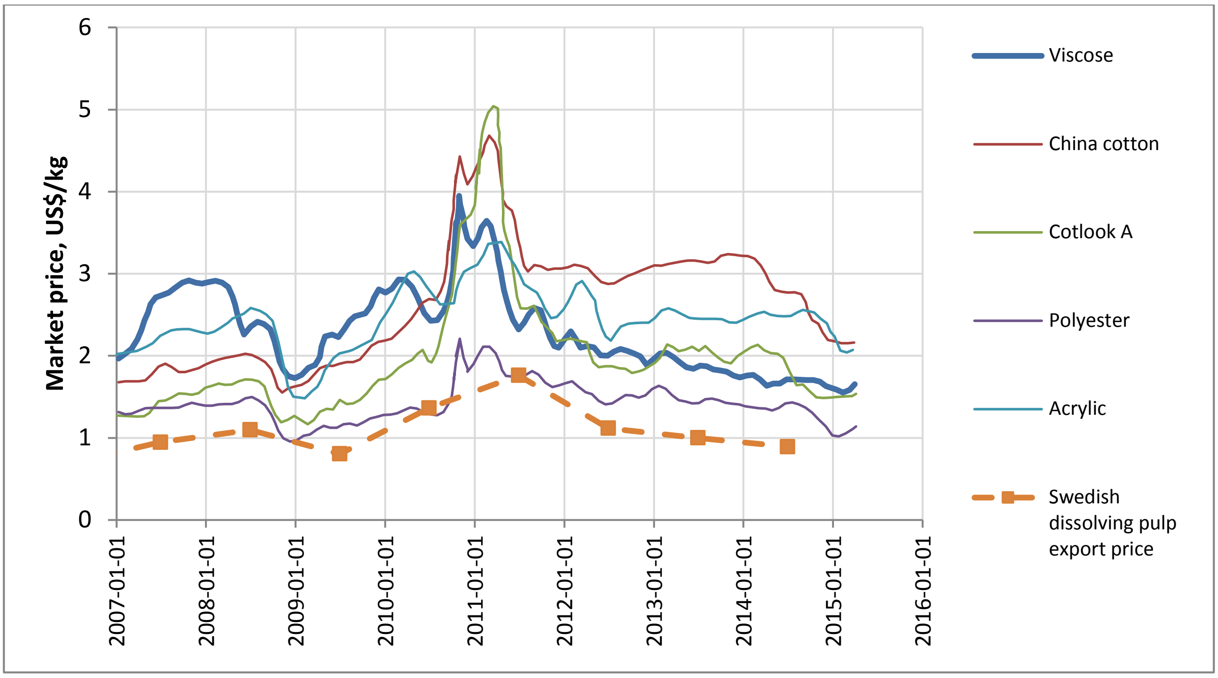


Figure 17. Staple fiber prices in Asia and annual average Swedish export price of dissolving pulp. Cotlook A is a cotton price index published by Cotton Outlook. Data shown for Cotlook A are based on Far East prices.

Source: PCI (2015), Statistics Sweden (2015b) and own calculations.

As for many value chains, the value addition accelerates towards the consumer end of the chain. While the dissolving pulp price is in the range of 5-10 SEK per kg, a piece of underwear weighing 70 grams that sell for 200 SEK would correspond to 2850 SEK per kg. By-products Sulphonated lignin (lignosulphonate) and dissolved hemicellulose are two important components in the spent pulping liquor. In the Domsjö mill, hemicellulose sugars are fermented into ethanol and part of the lignosulphonate is dried for external sale whereas the remainder is combusted for energy recovery. The lignosulphonate has its largest use as a dispersion agent, mainly applied in concrete. According to data from Norwegian biorefinery Borregard (Borregaard 2012-2015), the sales price for lignosulphonate products has increased over the past few years, thereby counteracting the downward trend for cellulose products (Figure 18).

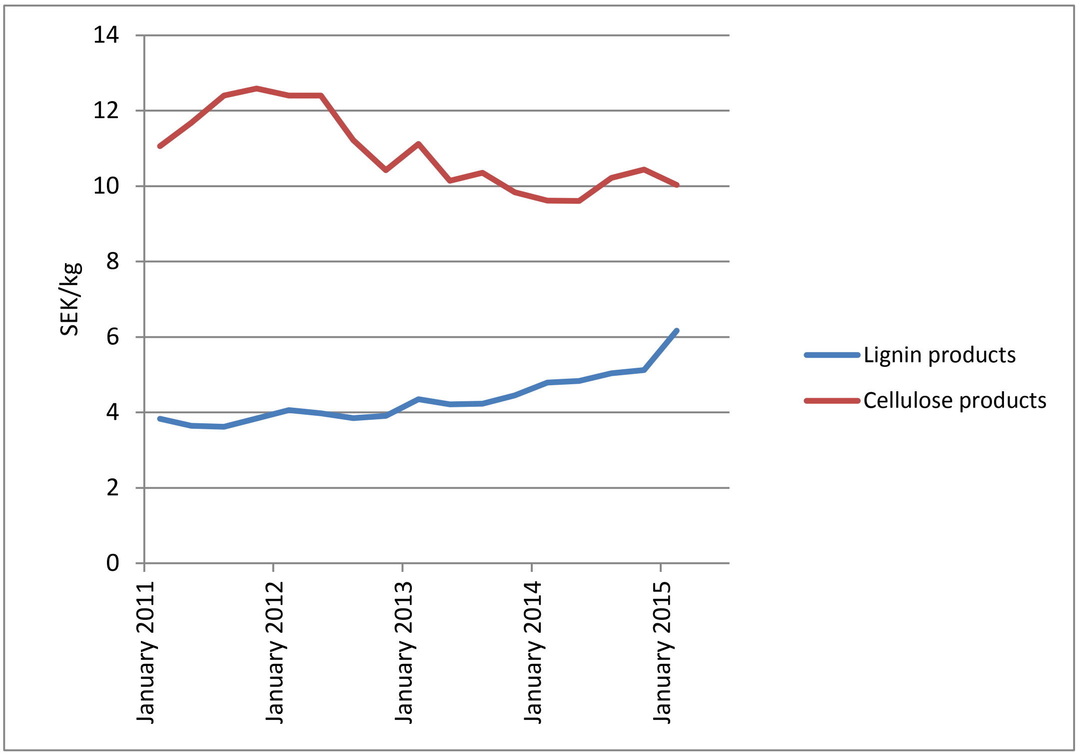


Figure 18. Gross average sales price of Borregard lignin products and specialty cellulose products. The lignin price refers to SEK/kgDM (Borregard 2012, 2013, 2014, 2015)

The ethanol produced in the Domsjö mill is sold to SEKAB, who upgrade it to motor fuel grade ethanol that is sold to markets mainly outside Sweden, where it can be sold with a premium as so called cellulosic ethanol, compared to ethanol from sugar and starch crops (Swedish Energy Agency 2014b). The Domsjö mill also produces biogas from its wastewater treatment plant. The gas is presently used for heat and power production, and not upgraded to vehicle-grade biogas. CO_2 is recovered from the ethanol fermentation process, where it is available in comparatively high concentrations. See also the section on ethanol production below.

4.3. ETHANOL VIA SACCHARIFICATION AND FERMENTATION

Ethanol is presently produced mainly through fermentation processes using starch- and sugar-based feedstock. Industrial ethanol production from wood has been performed historically, but new technologies are expected to have superior performance. These new technologies, which utilize lignocellulosic feedstock such as wood, and enzymatic treatments are currently in the phase of large-scale demonstration on several sites globally. The process described here is the one studied in the Skogskemi project and it is based on conversion of forests-based feedstock to ethanol through thermochemical pretreatment, saccharification, fermentation, dewatering and purification.

In order to increase the accessibility of the enzymes to the cellulose, the wood (chipped or saw dust) is pretreated using sulphur dioxide (SO_2) and steam explosion. Pretreatment is followed by simultaneous saccharification and fermentation, where most of the remaining cellulose is enzymatically hydrolyzed to glucose and the sugars are simultaneously fermented to ethanol by yeast. The residence time in this step is about 3-4 days. The ethanol produced is then at a concentration of 4-5% by weight and is increased to 93% by means of distillation and, if required, further to about 99% through a molecular sieve process.

Three co-products are generated in the process. Biogas, i.e. raw biogas, is produced from anaerobic digestion of the liquid effluent streams from the plant. The second co-product, a solid residue, containing mainly lignin, is washed and dewatered. The solid residue can be used as a fuel, e.g. in a CHP plant. The third co-product is carbon dioxide. Table 17 shows the approximate yields of the described process.

Table 17. Wood input and process outputs for a wood-based ethanol process

	50 kt EtOH/yr plant		Per tDM wood		Energy yield on wood (HHV)[b]
Input					
Wood	26	tDM	1000	kgDM	
Bark	2.86	tDM	110	kgDM	
Electricity	1.7	MW	65	kWh	
Fuel	38.2	MW	1469[a]	kWh	
Products					
Ethanol	6.1	t	235	kg	36%
Lignin	8.3	tDM	319	kgDM	41%
Biogas	3411	m^3	106	kg	17%
CO2	5.8	t	223	kg	
Remainder			117		

Source: Skogskemi sugar platform report, process integration report
a) Equivalent to approximately 200 kg of lignin
b) Higher heating value (HHV) basis

Ethanol for motor fuel use in Sweden is presently distributed in three forms (Swedish Energy Agency 2014b): ED95 for use in adapted diesel engines, E85 for use in adapted gasoline engines and as a low-level blend in gasoline. In Sweden, ED95 is produced only by SEKAB, who sell directly to large consumers. There is also a public ED95 refueling station in Stockholm. E85 and gasoline with low-level blend of ethanol is distributed via regular motor fuel companies via their refuel stations. Virtually all of the gasoline sold in Sweden is blended with about 5% of ethanol. European ethanol price trends are shown in Figure 19 and Swedish fuel prices at the pump is shown in Figure 20.

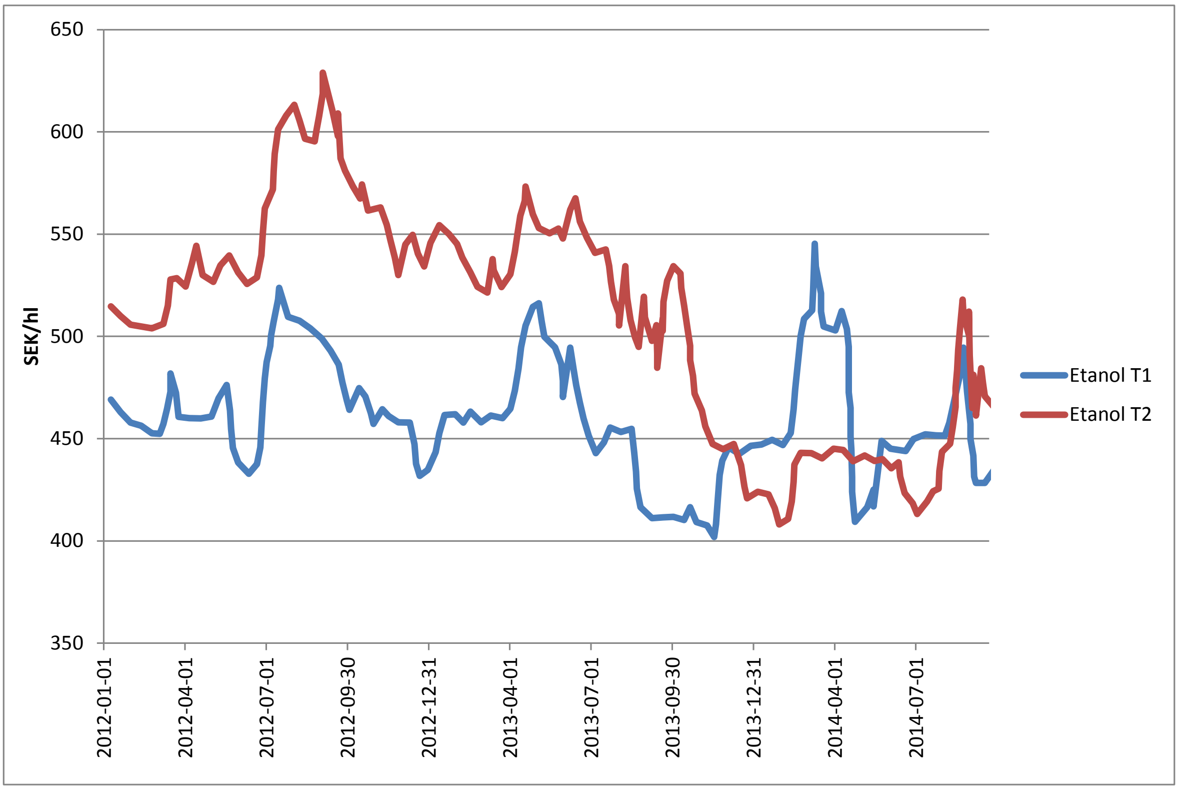


Figure 19. Ethanol prices for T1 ethanol and T2 ethanol, FOB ARA, in SEK/hl (Swedish Energy Agency 2014b)

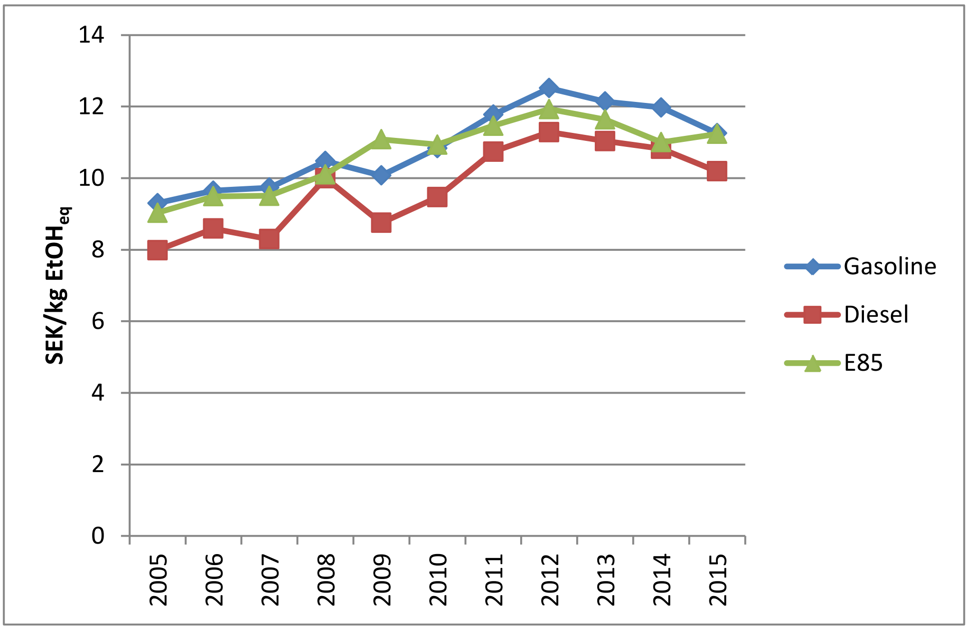


Figure 20. Annual average pump price of gasoline, diesel and E85, expressed in kg of ethanol equivalents, i.e. the price for an amount of the fuel that corresponds to 7.47 kWh of energy.

4.3.1. By-products

With an ethanol yield of around 25% (Table 17), on a mass basis (approximately 35% energy yield, on a higher heating value basis), it is clear that the by-product flows will represent an important part of the process output. The lignin produced in the described saccharification process is of a different nature than kraft lignin and lignosulphonate. Since the process of converting softwood into ethanol is not commercially developed, there is no developed market for the lignin by-product, and its economic value is uncertain. Other important by-product streams are biogas and CO_2.

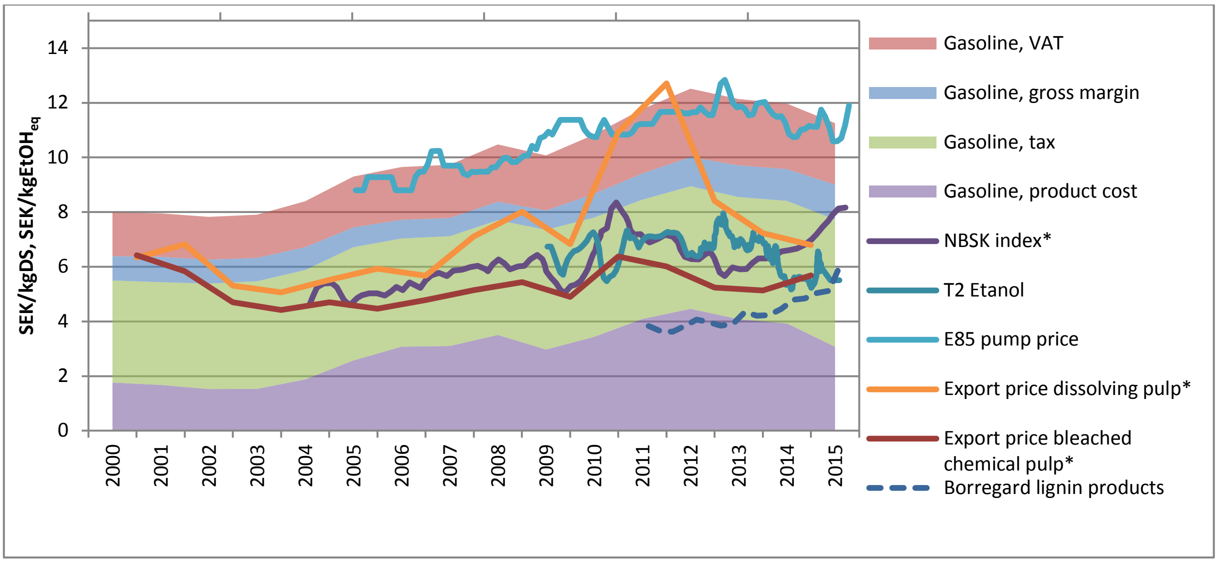
4.4. SUMMARY OF VALUE CHAINS

Whereas the reviewed processes (kraft pulping, dissolving cellulose pulping, ethanol production) have big differences, they are similar in that they imply a fractionation of the wood into its components, and that the cellulose or cellulose and hemicellulose is the basis for the main product. Table 18 summarizes the product yields from Tables 15-17 and Figure 21 gives a summary of historic prices of some key products and by-products in relation to the gasoline price. Here, the gasoline price and E85 price have been recalculated to SEK per kg of ethanol equivalent, i.e. the cost of a fuel amount equivalent to 7.47 kWh of energy. All other prices are given in SEK/kg.

Table 18. Summary of process yields for NBSK production, dissolving pulp production and ethanol production.

NBSK			**Dissolving pulp**			**Ethanol**		
Pulp	430	kgDM	Pulp	354	kgDM	Ethanol	235	kg
			Ethanol	30	kg			
Extractives etc.	21	kgDM	Pitch	12	kg			
			Biogas	22	kg	Biogas	106	kg
			CO_2	29	kg	CO_2	223	kg
Fiber loss etc.	37	kgDM						
			Lignosulphonate	161	kg	Lignin	319	kgDM
Remainder[a]	513	kgDM	Remainder[a]	391	kg	Remainder[a]	117	kgDM

a) Calculated as the difference between the wood input (1000 kgDM) and the product output.
See tables 15-17 for details.



* Recalculated to SEK/kgDM assuming 90% DM content.

Figure 21. Summary of historical prices for a range of biorefinery products compared to the gasoline price

Certain aspects of the feedstock quality requirements for the chemical pulping and ethanol production processes have been summarized in Table 19.

Table 19. Feedstock quality requirements for chemical pulping processes and for saccharification/fermentation processes.

	Feedstock composition	Physical properties	Other
Chemical pulping	The cellulose fibers are typically the desired component of the feedstock, but also lignin, hemicelluloses, and extractives may be utilized for co-products. Extractives such as resin may cause problems, especially in sulphite pulping. These problems can be reduced by adjusting the process conditions. Bark and impurities are detrimental for pulp quality and need to be removed.	Typically, stemwood chips are used. Knots and branchwood are generally undesirable. For the efficient impregnation of chemicals, chips should not be too dry, and the moisture content should be known for process control. Fiber properties, such as length, thickness, etc., may be very important, depending on the application. For textile cellulose applications, fiber properties are less important.	The particle size should be homogenous to control process conditions. Moisture variations are tolerable, but process optimization is easier with stable moisture content. While some heterogeneity in, for example, fiber properties may be beneficial, uniformity over time is important to maintain a constant product quality. Removal of bark and impurities is essential.
Hydrolysis	The content and composition of sugars is important. For fermentation to ethanol, glucose is preferred, followed by other hexoses. Pentoses are more difficult to ferment. There are three main groups of fermentation inhibitors: Furans (sugar degradation product); acids, especially acetic acid (mainly from hemicelluloses); and phenols (probably from lignin). Lignin is in general undesirable as it lowers sugar yields and has a negative effect on enzymatic hydrolysis. Extractives may also cause some problems in the process. Hydrolysis is relatively insensitive to impurities. Sand and rocks cause wear on equipment.	Moisture is not a big problem in ethanol production. However, the feedstock should not be too dry. Small particle size is in general desirable, but various sizes, such as chips and sawdust can be used. Fine materials may cause problems in filtering operations.	The particle size should be homogenous to control process conditions. Moisture variations are tolerable, but process optimization is easier with stable moisture content. Bark may cause problems according to some sources. Some sources say that bark and logging residues can be handled.

Finally, it can be noted that the down-stream value chains and end-product markets differ significantly for NBSK, dissolving pulp and ethanol. The market for fuel-grade ethanol is highly influenced by policy measures, such as fossil fuel taxation and ethanol import duties. The EU ethanol price has been lying above the gasoline product price, but below the Swedish gasoline product price including taxes. NBSK and dissolving pulp both have their niches where they provide desirable properties to the end product which distinguishes them from competing alternatives.

5. DISCUSSION AND CONCLUSIONS

The present study makes a brief descriptive review of forest-based economic flows and markets in retrospect. It does not attempt to model the consequences of counterfactual or future developments. Conclusions regarding such consequences and desirable developments and actions are speculative. The following discussion should, hence, not be interpreted as firm conclusions and recommendations, but rather hypotheses that would require more detailed studies.

Sawlogs and pulpwood account for approximately equal shares of the harvested roundwood volume (29700 Mm^3sub sawlogs and 28000 Mm^3sub pulpwood in 2009), whereas the value at roadside of the sawlogs is considerably higher (15500 MSEK vs 9200 MSEK in 2009). Adding that it is less costly to harvest and handle coarser logs than thinner logs, the sawlogs appear as the, clearly, most profitable product from the forest owners perspective. The total value of logging residues at roadside in 2009 was about 1100 MSEK, or about 4% of the total forest product value at roadside. About half of the logging residue value at roadside was spent on harvest and forwarding, whereas the corresponding value for roundwood is about a quarter. Thörnqvist (2007) found that saw timber generated about 80% of the forest owner's net income and pulpwood only 20%, with logging residues accounting for a mere 0.7%. All other things equal, the forest owner would prefer to produce more sawlogs and less pulpwood. However, the production of different assortments is intrinsically integrated. Thinning operations, which generate high shares of pulpwood, enhance the production of sawlogs and provide revenue in the short term to the forest owner. The economically optimal forest management strategy – and hence product mix - depends on a combination of, inter alia, market prices, forest productivity, management costs and discount rates. Also, the priorities may vary between different land owners, and they may act more or less rationally.

The different processing routes are interlinked. For example, the flow of by-products from sawmills to pulp industry represents a significant value. Both saw- mill and pulp mill residues are used for energy purposes, along with primary forest fuel. It has been estimated that 20% of the harvested forest volume is converted to sawn wood, 30% to pulp and 50% to energy (Holmberg, 2013). Sweden is a large net exporter of wood and products of wood as well as of paper and products of paper (c.f. Figure 9). The forest feedstock value as a share of the export value is larger for wood and wood products than for paper and paper products, indicating that the latter products require more (domestic) processing and hence contribute positively to added value and trade balance. Other studies have estimated that the value addition in construction is about 1.5 times the value of the sawn wood, whereas for carpentry and furniture it is some 20-30 times the sawn-wood value (Holmberg, 2013). The Swedish export of "Furniture and other manufactured goods" is approximately balanced by an equally large import.

The present forest industry works as a biorefinery in the sense that it converts forest resources into a range of products, where different fractions of the feedstock are used for different purposes. A general observation on refinery industries is that they tend to develop with increasing complexity over time, that continuous process improvements render the feedstock a key cost component and that the definition of an optimal feedstock product-mix is a non-trivial problem which may require sophisticated optimization algorithms (Lynd et al., 2005).

There appears to be a trade-off between feedstock quality requirements, processing cost and product quality. High-quality construction material can be produced with little processing from high-quality saw timber. With lower quality timber, processing losses will probably be larger, as more of the log has to be rejected or further processing has to be added – for example production of glue-lam beams – to give a product with acceptable properties for construction. Similarly, in pulping, more severe processing may produce a higher-priced pulp but with reduced yield and higher processing cost (c.f. for example mechanical pulp – kraft pulp – specialty cellulose). A lower pulp yield suggests that the yield of by-products is higher, and the value that can be generated from these side streams becomes increasingly important.

It would seem logic to make use of desired properties inherent to the feedstock. Thus, construction wood utilizes the mechanical strength of the wood and bleached kraft pulp utilizes the fiber properties. Cellulosic ethanol production would utilize the fact that cellulose is made up of sugar molecules whereas combustion for heat and power production utilizes the chemical energy bounded into the feedstock. Clearly, the macroscopic mechanical properties and fiber properties are feedstock specific to a higher extent than sugar content and energy content, and more specific requirements are put on the feedstock properties in order to utilize mechanical strength in construction wood and fiber strength in pulp, than in the recovery of chemical energy for heat and power.

We suggest that biorefining is about finding the optimal combination of feedstock requirements, processing cost, process flexibility, product mix and product properties. It should, however, be noted that each process stream entails costs in terms of piping, storage, handling etc. besides the direct process costs, and each new product requires organization around logistics, sales, etc. With increasing number of products, the volumes of individual product streams are reduced and benefits related to economies of scale are lost.

Finally, the market value of a product is dependent on the quality and usefulness of a product, but also on the price of competing alternatives. In the other end, feedstock prices are dependent on production costs, but also on its value in alternative applications. Eventually, the price for productive land is affected by competing land uses.

Logging residues is often mentioned as an under-utilized resource and there are, indeed, large volumes of logging residues that are presently not used. Statistics from the Swedish Forest Agency show that in Southern Sweden logging residues are taken out from more final fellings than in Northern Sweden. A majority of forest owners are in favor of taking out the logging residues; According to a survey (Norin & Tosterud, 2009) 74% of respondents could take out the logging residues next time they will perform final felling and only 11% that were directly adverse. A somewhat cautious attitude to logging residue extraction has as main reasons the low compensation levels and fear of damaging the soil and that production capacity will be compromised. Logging residues are at present, a relatively expensive feedstock, due to costly handling and transportation. It often has varying quality properties and contaminants from sand, dirt, etc. The logging residues represent a small income to the forest owner, who also has to take into account the risk that extraction of logging residues will adversely affect soil fertility etc. The money paid for logging residues by, for example, energy industries goes to the entrepreneurs that extract, comminute and transport the residues, rather than to the forest owner. Logging residues also meet competition from wood processing residues (bark, wood chips, saw dust, cutter shavings, etc.) which may be easier to handle, of uniform quality and less costly to produce and transport. The balance between supply of wood processing residues and demand for wood fuels affects the demand for logging residues. In parts of Sweden, only small amounts of logging residues are presently being utilized. Recent studies have shown (Joelsson et al., nd) that innovative systems for integrated harvest of round-wood and residues have the potential to reduce logging residue costs substantially. It is, however, not obvious that there is sufficient impetus to invest into these new systems, nor is it clear who has the incentives to drive the development.

A higher degree of processing of wood (more selective and adapted sawmilling, processing of wood into furniture etc., or a higher degree of pulp refinement etc.) is likely to yield more residues available for, for example, energy purposes. Hence, there is a possible synergy between development of higher-added-value products from wood and utilization of residues for other purposes.

5.1. CONSEQUENCES FOR MOTOR FUEL PRODUCTION

In general, forest-based motor fuel faces a number of challenges. The feedstock cost is relatively high, partly as a result of competition from other industries (sawmills, pulp mills, heat and power plants) and partly as a result of slow-growing wood and high processing and transportation costs. The processes for conversion of wood into motor fuel are, hitherto, relatively complex and expensive, compared to, for example, the processes for converting sugar, starch and oil crops into motor fuel. The feedstock basis is large, but there seems to be some development remaining for the processes to run efficiently and reliably on more difficult feedstock, such as logging residues and bark. Finally, petroleum-based fuels remain cheap, relative to the present production costs of forest-based fuels.

It would seem difficult for slow-growing boreal forest to compete with faster-growing crops unless it has other comparative advantages. Low competition for land and good availability of water may represent advantages. Fertilization and planting of forest on more fertile ground could significantly increase production rates, although land competition may be stronger on these soils. Nevertheless, motor fuel production from forest resources appears more likely to emerge as a by-product to other products, which make better use of the unique properties of boreal forest. The feedstock could appear in the forest as logging residues, but also as side streams in other forest-based industries. Logging residues already have an established application in heat and power production, and motor fuel production may find itself squeezed between the heat and power industry that can handle difficult fuels (e.g. logging residues) and the pulp and paper industry, that produces higher-value products from higher-quality feedstock (i.e. stemwood). There may be a niche for motor fuel production in some industrial by-products which are both easy to handle in the motor fuel production process and less suitable for high-value products.

New developments on the by-product side could also alter the situation. If a high-value application were to be found for hydrolysis lignin, for example, this could improve the attractiveness of the ethanol process, although ethanol would perhaps become the by-product and lignin the main product. Co-production of ethanol with high-value food and feed components, such as fatty acids and proteins, has also been discussed as an option.

In general, biorefining with integrated production of several products is generally found to be more efficient and with better economic performance than separate production. Integration with interdependence of several processes, however, increases the technical complexity and puts new demands on the business models. Integration of motor fuel production in a pulp mill means that the forest industry company either has to embark into a completely new area of business, or to let another actor closely into their own core activities. Also changes on the feedstock supply side could require important changes in business models. An integration of stemwood and logging residue supply has the potential to reduce the total supply cost, but it would imply that the (at present) low-value residue product is allowed to interfere with the (at present) high-value stemwood product. Would, for example, a pulp mill be willing to take on the complexity of accepting pulpwood with branches still attached, where debranching and handling of the branches would constitute a significant part of their feedstock handling activities? Also here the solution could be cooperation between several actors, but this would require good cooperation and new business models.

Clearly, as evidenced by several studies, including the Skogskemi project, the taxation of fossil motor fuels and tax exemption on renewable motor fuels has a decisive impact on the economic prospects for, for example, ethanol production. Other markets are not void of policy influence. The Asian cotton fiber market has been under political control; and environmental policy measures – such as fossil fuel taxation and green electricity certificates – influence the energy cost and by-product markets for pulp mills and other forest industries. However, the direct and large influence on motor fuel prices from policy measures makes this factor a key issue for motor fuels and any perceived uncertainty in the future development of the policy brings significant risks into the renewable motor fuels business. NBSK and dissolving pulp both have their niches where they provide desirable properties to the end product which distinguishes them from competing alternatives. The vehicle market, on the other hand, is totally adapted to gasoline and diesel fuel, and alternative fuels are generally disfavored by this type of lock-in. Niche markets may be found for the green property of renewable motor fuels, for example where consumers are willing to pay more for renewable fuels and with transport service providers with a high sustainability profile.

A sufficiently high price on renewable motor fuel combined with a sufficiently low price on other forest-based products would eventually change the situation in favor of forest-based motor fuel. Such a situation could, however, also bring about other changes in the economy which are difficult to foresee, and in any case, it does not appear as an attractive situation from a Swedish point of view.

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