

Dissertationes Forestales 203

Activity-based costing method in forest industry
– modelling the production and costs of sawing,
the pulp and paper industry, and energy production

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Academic dissertation

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ABSTRACT

Annual commercial roundwood removal in Finland has reached approximately 50 million m³, delivering almost 1.6 billion Euros of stumpage earnings to forest owners. The aim of this dissertation is to study and model the production costs of saw-, pulp and paper mills and the combined heat and power (CHP) plant, which are the branches of forest industry that create most of the industry's wood-paying capability. The modelling was performed by implementing the activity-based costing (ABC) method for virtual greenfield mills located in Finland.

Firstly, according to the principles of ABC, mill productions were divided into processes. The sawmills consisted of eight processes, while the pulp and paper mills of ten each and the CHP plant consisted of four processes. Secondly, all required production resources of each process were defined and quantified. Thirdly, the costs of each process caused by using the wood processing or energy use resources were allocated to the products or raw materials with cost drivers.

Results of the example calculations indicated that the cost structures of the studied mills shared some similarities: wood, pulp or paper drying was a relatively expensive process. The share of drying was 40%, 39% and 18% of the annual costs in the sawmill, pulp mill and paper mill, respectively. The fluidized bed boiler represented 47% of the total costs of the CHP plant. Taking into consideration the practical limitations of the test calculations, the profitability of the pulp and paper mills and CHP plant were on a healthy level. The sawmilling case was left out of the profit calculations due to lack of market price information. According to the results, ABC was well-suited to the demands of forest industry. The models provide useful tools for cost-based decision-making for both forestry specialists and the forest industry. The results indicate that the sawing pattern is a very important cost factor in sawmilling, while energy production was crucial for the pulp and paper industry and the utilization rate was in a key position for CHP. From the forest industry viewpoint the models directly aid in performance analyses; results of the calculations revealed that the relatively high share of drying costs in the industry signals that the most cost-effective improvements could be found from energy savings, which has been the tendency in past years. These results can be combined with the forest end of the supply chain, whereby forest engineers have access to better control over tree-bucking optimization and different parallel value chains of forestry can be compared and evaluated with high accuracy.

Keywords: Activity-based costing, production costs, profits, process, sawmill, pulp mill, paper mill, combined heat and power.

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In Koittankoski, Merikarvia, September 2015

Heikki Korpunen

LIST OF ORIGINAL ARTICLES

This dissertation is based on the following four (I–IV) articles, which are referred to by their Roman numerals in the text throughout this summary. Articles are reprinted with the kind permissions of publishers.

- I Korpunen H., Mochan S., Uusitalo J. (2010). An activity-based costing method for sawmilling. *Forest Products Journal* 60(5). pp. 420–431.
DOI: <http://dx.doi.org/10.13073/0015-7473-60.5.420>
- II Korpunen H., Virtanen P., Dahl O., Jylhä P., Uusitalo J. (2012). An activity-based cost calculation for a kraft pulp mill. *Tappi Journal* 11(9). pp. 19–27.
<http://www.tappi.org/Bookstore/Technical-Papers/Journal-Articles/TAPPI-JOURNAL/Archives/2012/September/Table-of-Contents/An-activity-based-cost-calculation-for-a-kraft-pulp-mill-TA.aspx>
- III Korpunen H., Paltakari J. (2013). Testing an activity-based costing model with a virtual paper mill. *Nordic Pulp and Paper Research Journal*. *Nordic Pulp & Paper Research Journal* 28(1). pp. 146–155.
DOI:10.3183/NPPRJ-2013-28-01-p146-155
- IV Korpunen H., Raiko R. (2014). Testing Activity-Based Costing to Large-Scale Combined Heat and Power Plant using Bioenergy. *International Journal of Energy Research* 38(3). pp. 339–349.
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Declaration of responsibilities and contributions of PhD (For.) student Heikki Korpunen

Heikki Korpunen is fully responsible for the summary of the doctoral thesis “Activity-based costing in forest industry”.

In study I, Heikki Korpunen was mainly responsible for planning the study, collecting the cost information data from machinery manufacturers, applying the sawing patterns from previous studies, building the costing model, cost calculations, analyzing the data and interpreting the results. He was the main writer and reviser of the manuscript.

In study II, Heikki Korpunen was mainly responsible for planning the study and the cost calculation model, data analysis and interpretations of the results. He was also the main writer and reviser of the manuscript.

In study III, Heikki Korpunen was mainly responsible for planning the study, initializing the cost calculation model, data analysis and interpreting the results. He was also the main writer and reviser of the manuscript.

In study IV, Heikki Korpunen was mainly responsible for planning the study, implementing the cost model, calculating the costs and interpreting the results. He was also the main writer and reviser of the manuscript.

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1 INTRODUCTION

1.1 Research of supply chain management in forestry

In the fields of forest engineering and wood technology, the wood value chains can be considered to begin from the timber purchase, where either the felling rights or already felled and bucked timber is purchased (Uusitalo 2010). Forest engineering covers the path of timber all the way to the mill gate. Wood technology takes over the logistic chain when the actual wood raw material processing begins (Kärkkäinen 2003).

Generally, in the areas of research the wood processing and energy industry and forestry operations have been handled practically as separate operations. However, it is obvious that the two operations are in close junction with each other. The industry acts as a customer and places wood assortment orders whereas the wood supply management serves the industry by delivering the required amounts of wood to the right places at the right time. The customer-seller situation is usually more or less artificial, as both are basically departments under the same organization. An example of forestry supply chains is presented in Figure 1.

Supply chain management (SCM) is sometimes considered to only handle manufacturing or purely logistic issues, as it should emphasize the broader view of business, from raw material procurement to end user deliveries (Cooper et al. 1997). As in many other SCM research fields, forest products researchers meet challenges caused by a wide variety of end products and inter-organizational actions. As each end product creates its own supply or

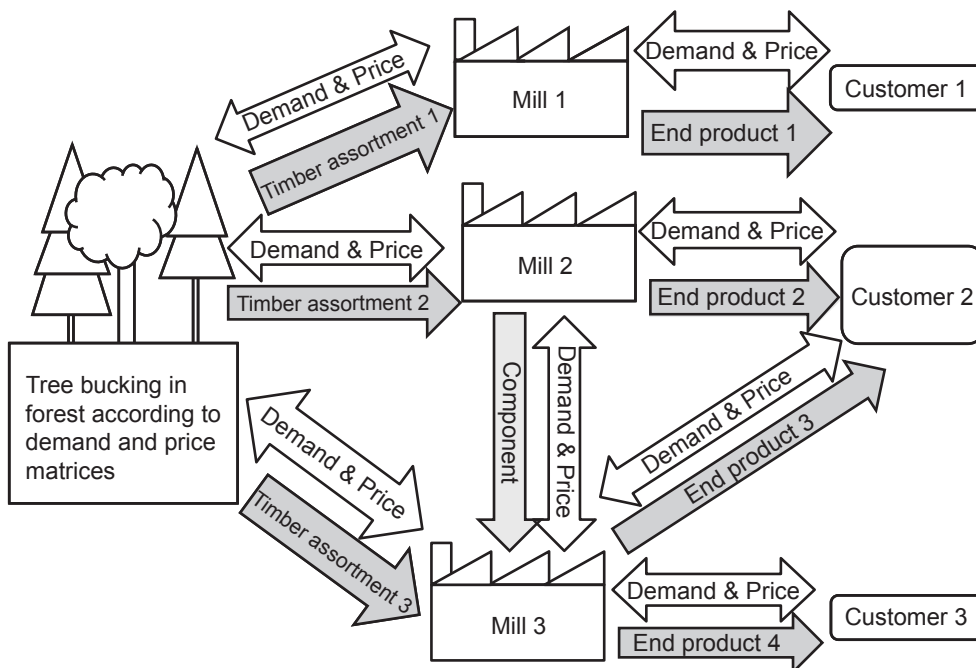


Figure 1. A schematic drawing of supply chains in forest industry from the forest to the customers. Grey arrows represent material flows and white arrows information flows of the system.

value chain beginning from the forest, the evaluation of possible parallel chains is difficult. With adaptive tree-bucking control each tree stem can be initially bucked theoretically in limitless ways and each bucking decision affects the next one.

The supply chain was described by Mentzer et al. (2001) as a set of three or more actors involved in upstream and downstream flows of resources, services and/or information from a source to a customer. SCM has become the general describing term for managing this interactive chain of raw material delivery to mills. SCM interprets the logistical interactions that take place between marketing, logistics and production. The basic idea of SCM is to control all material flow activities and raw material transformations to end user products, also including the information flows related to activities and material flows (Stadler 2005). For example, Whicker et al. (2004) studied supply chain performance and showed that knowledge concerning cost accumulation reveals useful information for improvements.

Forest researchers, mainly in the field of forest engineering, have successfully conducted SCM studies in the context of wood procurement (Uusitalo 2005). Wood raw material procurement and delivery to mills has been a key interest. Many successful studies have been conducted in this field, e.g. Nurminen et al. (2006, 2009) studied the time consumption of cut-to-length (CTL) harvesting, forwarding and timber trucking. The study also handled the effect of the timber assortment amounts on the unit costs of work. Similar studies have also been conducted worldwide, e.g. Jungmeier et al. (2002), Carlsson et al. (2009), Beaudoin et al. (2010) and Abbas et al. (2013) studied timber procurement in different logging environments and also compared harvesting methods. The logistics of these studies handled tree harvesting, forwarding and long-distance transportation, and the material upstream flow from the wood processing and energy use viewpoints. However, SCM studies only briefly handled the information flow from mills to forests. As defined above, the supply chains deliver information both upstream and downstream meaning that the information from mills to forests should be taken more into consideration.

Wood orders from mills are transformed into demand and price matrices. These matrices control tree bucking in harvesting, and are given as fixed information, without detailed and profound exploration of causal connections of the market situation and raw material supply. The lack of information handling the causal connections between end product markets and raw material supply are not the fault of researchers: when forest engineers calculate the best possible profits for tree bucking decisions, they usually just do not have exact information concerning the customer end of the logistic chain. Timber assortment prices are usually received from general market statistics. However, the statistical information is fixed for a certain market situation and may contain some speculations. Wood-consuming mills can be seen as black boxes that buy wood for a certain price, quantity and quality, and produce their own products, but the interface between the forests and mills has traditionally been without determinate focus. As indicated in the study by Hsu and Hsu (2008), information flows must be detailed and effective concerning both the upstream and downstream logistic chains for clear causal relations.

Fortunately for forest engineers, support from other forestry research areas has increased recently. Rapid development in the fields of geoinformation and remote sensing, especially in airborne laser measurements, has also offered new tools for forest engineers needing accurate pre-harvest information from logging sites to support tree-bucking optimization (Holopainen et al. 2014). Laroze (1999) determined tree-bucking optimization as a three-level problem (stem, stand and forest levels), where tree-bucking should be performed as efficiently as possible at each level. Stem-level optimization is performed at the logging site, where the top part properties of the stem are predicted according to properties of the butt logs. Stand-

and forest-level tree-bucking optimization similarly requires pre-harvest information for the best possible prediction and planning of harvesting and tree forwarding. Furthermore, taking into consideration the fast development of remote sensing, the new technology will offer the needed stand- and forest-level information for the large-scale planning of harvesting operations (Holopainen et al. 2010). This will significantly support supply chain management.

1. 2 Economic importance of forest industry in Finland

The annual commercial domestic roundwood trade in Finland reached 51.5 million m³ in 2012, 39.7 million of which was the private forest owners' share (Ylitalo 2013). The most important timber assortments are Norway spruce (*Picea abies* L. Karst.) and Scots pine (*Pinus sylvestris* L.) sawlogs and pulplogs, which cover approximately 82% of the total roundwood markets. Furthermore, from the forest owners' viewpoint, sawmilling is the most important branch within the Finnish forest industry. Of the stumpage earnings in 2012, nearly 70% of the wood sellers' incomes were paid by sawmills, which in volume equates to roughly 42% of all market loggings in Finland (Ylitalo 2013). By comparing these last two percentages, it is obvious that sawmilling both requires and is willing to pay for the highest quality of wood assortments.

Saw, pulp and paper mills are in close connection with each other in the Nordic countries, where strategic decisions have been optimized for more than one individual facility. Unit locations have been selected to enable resource use as efficiently as possible. For example, the sawing yield is approximately 50%, meaning that the process produces a lot of woodchips that are directly useless for sawmills (Rikala 2003; Spelter et al. 2007). However, the chips are chipped from the surface of the sawlogs, which is a highly favourable raw material for the pulp and paper industry because of the long tracheid cells (Lindström 1997). This valuable stream of raw materials is nowadays taken carefully into account when the location of a new plant is planned. Currently, optimized supply chains usually mean that the transportation costs are the lowest possible and thus saw, pulp and paper mills are usually located close to each other (Carlsson and Rönnqvist 2005).

The woodchip stream from sawmills represents a minority of the total wood flow for the pulp and paper industry, despite its importance as a wood fibre raw material. Over 29 million m³ of pulpwood was harvested from Finnish forests in 2012. The amount equals nearly 57% of the total annual commercial roundwood removals. When comparing to sawmills, the pulp and paper mills pay relatively less for the pulpwood: the 29 million m³ equals 28% of the gross stumpage earnings to forest owners. The quality requirements are much lower and also the unit costs of harvesting are higher for pulpwood. Value-adding of the pulp and paper industries was 2.8 billion Euros in 2012, when the same figure was 1.1 billion Euros for the wood products industry (Ylitalo 2013). When comparing the value-addings and stumpage costs, the pulp and paper mills are able to process cheaper wood into more expensive goods than mechanical processes.

In addition to the mechanical and chemical forest industry, the energy sector has also noticed the possibilities of the bioindustry; CHP plants can provide both heat and electricity for scattered residential areas and improve local energy self-sufficiency. Forest fuel consumption has steadily increased in Finland, and according to current political will, the tendency remains the same. Cleantech (a term for technology that aims to cut down dependence on non-renewable resources and improve sustainability), has grown globally to an over 1600-billion Euro business with an annual growth of more than 10%. Renewable bioenergy has a key

role in cleantech. The future demand for renewable energy in the European Union (EU) is expected to be 179 GW by 2020. The Finnish government has stated that cleantech will be one of the spearheads in the national industrial policy (Kansallinen ilmastostrategia 2013). The government is therefore concentrating on research and development projects for the cogeneration of heat and power. Supporting domestic bioenergy production, consumption and technological development is one basis for maintaining a functioning exporting business. These renewable energy assets have meant a significant increase in the bioenergy consumption of Finland. Although only 4% of the gross stumpage earnings of forest owners is derived from energywood, the aim is to increase its use from 8.2 (in 2012) to 13 million m³ annually by 2020 (Ylitalo 2013).

Domestic wood markets have a socio-economic importance to Finland: wood procurement, processing and energy use offers work for rural areas. Fortunately, Finnish forest industry has also recently declared a plan to invest in a new pulp and bioproduct mill in Äänekoski (Thúren 2014). The pulp and paper industries are significant supporters of the surrounding economic environment; the total employment multiplier rate is the highest, (4.04) among all Finnish industry (total average 2.50) (Ylitalo 2013). This means that each pulp and paper industry worker cooperates with four workers in supporting industries to form a fully functioning value chain. The sawmilling industry is also above average, as the employment multiplier rate was 3.60 in 2012.

The economic return of private forest owners is strongly dependent on the paying capability of the forest industry, e.g. in 2012 the total investment return in wood production was -3%, which was due to a decrement in stumpage prices (Ylitalo 2013). Since stumpage prices determine the economic feasibility of every forest owner, it is crucial that the costs and revenues of forest industry are set in an equitable manner.

Finnish government established a new national bioeconomy strategy for improving the use of renewable resources (The Finnish Bioeconomy Strategy 2014). The strategy recommends that the future of bioeconomy in Finland must be based on a competitive operating environment, new businesses, competence and accessibility, and sustainability from bioeconomy. Especially the competence endorsed in the Strategy must be evaluated by economic factors, meaning that costs and profits from the industry must be predetermined with satisfactory accuracy.

The forest industry is significant to Finnish economy and developing the bioeconomy for maximizing the potential of the branch of industry is concurrently necessary. Therefore, a certain need exists for more detailed studies concerning value-adding in wood supply chains.

1.3 Estimating economic performance by costing

According to Viitala and Jylhä (2007), product or service pricing can be done using three methods: markets set the price, production cost-based price, or target-costing price. Market prices are formed through supply and demand, and production costs must be adapted in ways that allow for profitable production. Production cost-based prices take the actual existing costs as a basic value and tend to set a minimum level for prices. Target-pricing the markets sets the prices and the costs are adapted through quality management or product quantity. Of these price-setting methods, production cost-based is perhaps the most controllable and interesting method, despite the markets eventually either approving or rejecting the price. Production costs are basically the easiest to influence, yet cost controlling is demanding.

Productivity measurement is important for companies in addition to pricing for controlling

business success. Furthermore, improving productivity seems to be a guideline for every action made in any branch of industry. According to Sink (1985), economic productivity equals output divided by input. Productivity can additionally be measured based on different production factors beginning with an individual actor and progressing to the national level, although the measurement units may vary. Profitability is another general indicator of the competitiveness of any economic unit, which means the ratio between sales and costs. Profitability is a close relative of productivity as both measure the performance of a company (Rantanen 1995). Furthermore, improving productivity increases profitability.

Consequently, if an organization wishes to improve profitability, a productivity improvement is a common way of achieving that goal, as a higher output-input ratio means cost-effectiveness. To measure and manage both productivity and profitability, an organization must be able to follow these factors.

A successful organization has a detailed and up-to-date information system of the current financial situation. Most companies must have official accountancy, which is controlled by legislations. The accountancy is for delivering financial information and records to fiscal authorities, stakeholders, and for general interest. However, accounting does not deliver sufficient information for the internal purposes of a company. According to Cooper and Kaplan (1988), relying merely on accounting information especially in a multiproduct environment may lead to false pricing because accounting-based cost estimations lack information for the overhead cost allocations of products or product groups. For internal purposes, such as production planning and pricing, an organization must have a practical system for analyzing the production system, estimating the costs and allocating them reasonably to the products or services. If the costing is incorrect, the pricing will be false and this will eventually lead to either poor profitability or lack of demand.

Turney (2005) lists six indicators that should draw attention to the validity of the current costing system: 1: Management is skeptical concerning costing information; 2: Selling and marketing departments do not want to implement costing information in the planning or pricing of novel products; 3: Sales are going up but profits down; 4: The mid-level management of a company is using a second, unofficial costing system; 5: Development projects are unable to produce anticipated cost reductions; 6: Customers are picking cherries from the company's product pallet. If even one of these indicators is noticed, the problem should be handled forcefully.

Malmi (1999) studied the diffusion of a novel cost calculation method in Finnish firms. He projected the reasons for adapting novel costing to be based on three motives: efficiency, forced selection and fashion and fad. The first-wave adaptors explained the initialization of a new costing method mostly with efficient-related grounds, such as an existing costing method was unreliable or useful for management. The other motives were clearly secondary both in time and rationality. Rantanen (1995) also points out that the usefulness of a new costing method is eventually measured with the potential of gaining more profit via a possible switching of the method.

When the introduction of a new costing system is planned by an organization, the goals of the procedure must be set. Firstly, to avoid change resistance among users of the costing information an answer must be delivered to the question "What for, and why are we developing this new costing system?". The costing method must be easy to use and also economical for the users: the method is not worthwhile if its utilization demands more costs than it is delivering profits.

According to Malmi (1997) and Drennan and Kelly (2002), despite economic motives being the most important ones when defining the implementation of a new costing method,

several other background factors must also be taken into consideration if the success of a project is to be ensured. The first workers to meet the consequences of company culture changes may have different motives for adapting their behaviour; some workers may see the change as a possibility of upgrading their own position while others may see the change as a severe threat to their own careers. These nearly opposite reactions must be identified in an early planning stage of the development project as possible and handled in such a manner as to bring satisfactory results for everyone involved.

1.4 Activity-based costing

Traditional costing methods, where costs are calculated for groups of various processes at a time, were sufficient for most users in the past, as a mill or plant produced only one or two similar products. However, once production began to consist of a bundle of various products, costing accuracy was not sufficient and pricing was not up to date anymore. Forest industry is one example of this differentiation: pulp mills were converted to multi-product biorefineries where pulp production may generate less than half of the annual turnover. According to Hogg and Jöbstl (2008) one example of the costing systems used by the forest industry is the standard costing method. This method delivers relative costing levels that can only indicate ratios between executed and anticipated production costs. This method was originally developed for price setting in labour-intensive industries.

New method development began during the mid-1980s, when managers realized that the costing methods in use were delivering misleading information (Turney 2005). Managers began realizing that the costing methods, where costs were allocated to products or services according to working hours, were not accurate since automatization and mechanization was changing the very bases of the old methods (Rantanen 1995; Malmi 1997). Furthermore, Nurminen et al. (2009) noted that traditional costing will deliver false results if some product or product group needs special treatments in the manufacturing processes. Another, more reliable way of allocating costs must be invented.

ABC was developed as an answer to the cost allocation problems. The entire ABC theory is based on the presumption that costs must be allocated to products in actual relation to their resource consumption (Kaplan and Anderson 2004). The cost object is in the core of the ABC method is, and it is the target of the cost calculation (Turney 2005). Information gathering begins once the cost objects are determined; every relevant information flow must be detected and tools for cost and production data collection have to be selected. General ledgers and annual production plans are a good basis for building the models (Turney 2005). Time and productivity studies may also be effective for ascertaining currently invisible data required in costing studies.

The processes are defined next. Production should be divided into practical processes: not too detailed (updating is arduous) or too general (results are not accurate enough). Production is usually divided into processes or divisions e.g. for production and labour planning (Smook 2002), which can also be used for ABC purposes. Each process has one or more activities that describe the actions needed for accomplishing a task. The essential idea of ABC is that activities cause production costs, which are then allocated to products in accordance to resource consumption. The term 'cost driver' outlines the relationship between the cost object and resource consumption (Turney 2005). There are no clear norms for selecting the cost driver, e.g. it can be a lead time of a product as in time-driven ABC (Kaplan and Anderson 2004) or even a combination of several independent factors in the activity (Homburg 2001). An illustrative presentation of implementing ABC in a company is presented in Figure 2.

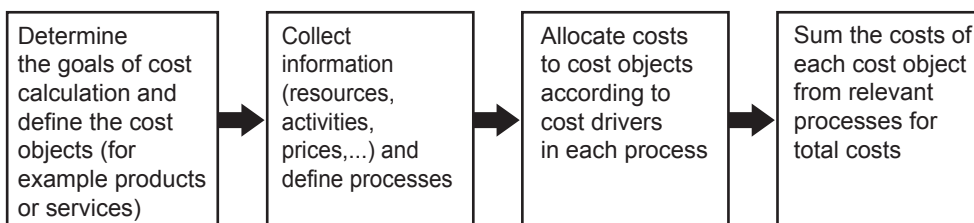


Figure 2. An example of the initialization process of activity-based costing at the company level.

ABC does not differentiate between fixed and variable costs, both are summed for the cost pools of each process and furthermore allocated to the products (Turney 2005). The overhead costs, which may be problematic for handling and allocating processes and products, are also manageable since each process or cost pool receives its own share. Some organizations therefore initially began using ABC for better controlling of overhead costs (Cobb et al. 1993; Innes and Mitchell 1995; Selto 1995).

The benefits of ABC were noticed by a variety of organizations. For example governmental (Brown et al. 1999), healthcare (Arnaboldi and Lapsley 2005), library (Ellis-Newman 2003) and logistical organizations (Pirttilä and Hautaniemi 1994) adopted the ABC in the early stages of method evolution. All of the changes in these organizations were mainly justified by purposes of finding excessive production costs and productivity gaps.

There are indications that the ABC method is sometimes considered expensive for implementing and maintaining in comparison to traditional costing methods where the need for detailed information is smaller (Malmi 1999). The additional costs may be incurred from using consultants during the implementation phase or by purchasing new software or hardware for information collection and calculations depending on the required level of automation. Despite ABC not requiring high-tech applications on the basic technological level, calculations can be performed using spreadsheet programmes with basic computing skills, but the method must be familiar to the user.

1.5 Costing in forest industry

The forest industry does not differ much from other branches of industries; public costing studies that both present the application of a costing method and test the method with case studies are rarities. The ABC does not differ in this sense from other costing method studies. Several studies are focused on developing or testing theories on some small parts of production and plant-level costing information is needed. This was noted e.g. by Ghosal and Nair-Reichert (2009).

Sathre and Gustavsson (2009) focused on value-adding in the forest industry, and according to their study wood is a special raw material as many different products can be made from a single renewable resource. This diversity therefore offers great potential in the value-adding of the industry. Lantz (2005) studied investment feasibility in Canadian forest industry from the value-adding viewpoint, and observed that the investments on the production scale was generally the most beneficial act, as investing in cooperation between other plants was most beneficial to the pulp and paper industry.

Costing studies in sawmilling have been rather specific. For example Howard (1993) only studied the variable costs of sawmilling and Hakala (1992) tested the effect of sawlog size on the economics of sawing. Wessels and Vermaas (1998) presented an ABC model for sawmills, with a finding that implementing a new costing model may deliver useful information but sometimes with a high price tag. Rappold (2006) tested the suitability of the ABC method in certain processes of two hardwood sawmills, and compared the results to traditional costing methods. According to the study, ABC was well-suited for sawmilling. The method was only tested for log debarking, sawing and green sorting, yet the results indicated that in comparison to traditional costing, ABC revealed skewing in the cost structures of some lumber assortments, as production costs of the highest marginal products were underestimated with traditional calculations. This was due to higher resource consumption that was neglected by traditional costing. A similar observation was made by Tunes et al. (2008) when they studied the effects of different cost allocations and recognized that the different allocation methods emphasize product groups in different ways.

Process-focused cost research has been carried out within the pulp and paper industry by e.g. Castro and Doyle (2004), who focused on benchmarking the pulping process. Frei et al. (2006) focused on costing of a novel method for waste material flow treatment at pulp and paper mills. Many useful studies have been conducted in the area of energy production in pulp- and papermaking, e.g. Farla et al. (1997) analyzed the development of energy efficiency in eight pulp- and paper-producing countries. Thollander and Ottosson (2008) studied the driving forces of cost-effective energy investments in the Swedish pulp and paper industry. ABC was used by Fogelholm and Bescherer (2006), who found the costing method useful when combining it with the idea of continuous improvement (the Kaizen philosophy) in pulp and paper production. Both Laflamme-Mayer et al. (2008) and Janssen and Stuart (2011) also presented their own ABC systems for the pulp and paper industry, which could be used as decision support tools in supply chain management.

The close connection between energy production and the pulp and paper industry can be seen in many energy studies, where the CHP plants and energy production in general have been optimized for paper mills (e.g. Gale 2006; Marshman et al. 2010; Ahmadi et al. 2012). Raslavičius and Bazaras (2010) tested the financial risk levels and economic feasibility of biofuels with a small-scale CHP plant in a partly theoretical environment. Furthermore, several energy economic studies have focused on selecting the right scale and fuel-mix for each case, e.g. Dornburg and Faaij (2001) and Wei et al. (2011). Trygg et al. (2008) tested the economics of a small-scale power plant with ABC and searched correlations between the workloads and production costs.

1. 6 Research strategies of costing studies in industrial management

Furthermore, none of the previously mentioned ABC papers delivered an actual plant-level costing model with example calculations. Theoretical models are useful, but the initialization of any costing method would be significantly more meaningful with an illustration of their uses and results. These requirements must be taken into account when selecting the most suitable research approach. The evaluation and selection of the research approach or paradigm must be made before the actual study, so as to gain reliable results that are comparable with other references.

The research paradigms in industrial management can be divided into five categories (Olkkonen 1993): formal conceptual research strategy, nomothetic strategy, action-oriented

strategy, constructive strategy and decision-making methodological strategy. The usefulness of these paradigms can be estimated by comparing their ability to produce suitable results for the research problem at hand. In formal conceptual strategy definitions exist at the abstract level and do not contain measurable attributes, and the paradigm is used for theory building (Wacker 2004). Shefir and Kolarik (1981) studied life cycle costing from the viewpoint of formal conceptual strategy and issued guidelines on how to adapt costing in many areas of economics. Nomothetic strategy is a quantitative approach, where the aim is to make objective observations of the test subjects and to create general symmetrical rules (Chelpa 2005). Christensen and Demski (1995) studied some elementary code differences between the ABC and traditional costing methods. According to Ford and Ogilvie (1997), the researcher is an active observer of a research case in the action-oriented strategy, and makes conclusions and future recommendations according to the experience analysis. The action-oriented paradigm was used e.g. by Boehm (1991), who identified the risks and studied the costs of computer software development. Constructive strategy focuses on problem-solving by innovating and developing completely new models or mathematical programmes for specific cases in organizations (Kasanen et al. 1993). Lindholm (2008) adapted the constructive strategy approach for problem-solving in a real-life company management case.

The fifth research approach, the decision-making strategy, produces solutions for explicit problems on a more general level and thus it is a suitable approach for a cost modelling study. The methodology delivers practical information for decision-makers at a specified point in time (Schulper and Fenwick 2000). In the decision-making methodology, the problem is firstly specified, then reconstructed into mathematical form and next tested with case studies (Olkkonen, 1993). Finally, the mathematical forms and case study results are evaluated and further suggestions for developing decision-making tools are made. The decision-making methodology was successfully used by Wang et al. (2004) in a supply chain management study from the manufacturing viewpoint. Tsai and Hung (2009) also applied the same approach when testing ABC with green supply chain management. The decision-making research paradigm was subsequently selected for this dissertation.

1.7 Work aims

According to previous studies, activity-based costing is a promising method for economic analyses in multi-product industries such as the forest industry. Understanding the cost structures of forest industry could improve the supply chain management of forestry. This study was thus formulated with four main aims: Firstly to adapt the ABC method to saw-, pulp and paper mills and the CHP plant for cost modelling. Secondly to test the ABC models using virtual plants. The second aim was further divided into defining the resources of production processes and calculating the production costs of each facility. Thirdly to also test the profits of three of the studied facilities (pulp mill, paper mill and CHP plant). Fourthly to evaluate the total results from the forestry viewpoint; what effects can be achieved with better understanding of cost structures and price formation in the earlier stages of value chains.

Allocation of the four major aims to the individual studies forms the structures of each paper as follows: The aims of the sawmilling study (later referred to as paper I) were to define the processes and calculate the production costs of a modern mechanized softwood sawmill, and to test the effect of sawing pattern on the costs with case studies 1 and 2. The amount of sawn lumber was reduced from case 1 to case 2 to demonstrate both the applicability of the costing model and the actual effect on the sawing costs.

The pulp mill study (paper II) focused on defining production processes and costs of market pulp production. Additionally, one of the aims of paper II was to calculate the profits and test the property effects of Scots pine pulplogs with the costs and profits of pulp making in case studies 1 and 2. With the pulp milling case 1, the logs were procured from thinnings and in case 2 the logs originated from clear-cuttings.

The third study concentrated on the processes, costs and profits of papermaking (paper III). The study also demonstrated the effect of Norway spruce log properties to the profitability of a paper mill in case studies 1 and 2. The paper mill case study 1 handled the costs of production when the logs were procured from clear-cuttings, while in case 2 the logs originated from thinnings.

The fourth study handled wood-based energy production in a large-scale combined heat and power plant (paper IV). The study modelled the production processes, costs and also the profits of producing heat and electricity from mainly wood-based fuels. The models were tested using case studies where the tree species of the fuel-mix varied from Norway spruce to Scots pine. The effects of the utilization and interest rates were also tested.

These four studies provide information for decision-making at the strategic level. The evaluation of the most profitable wood value chain for each tree in a forest becomes easier as the production models of plants, costs and profits are made comparable with each other.

2 MATERIAL AND METHODS

As mentioned above, this dissertation was divided into four studies (papers I–IV) and each paper was designated its own specific aims. These studies were carried out partially simultaneously during 2009–2015. A simplified graph (Figure 3) illustrates the execution of each study.

2.1 Data collection and sources

The four study subjects, the sawmill, pulp mill, paper mill and CHP plant, were selected for the cost calculations because of their significance to Finnish wood users. However, the models were not only fixed for Finnish or Nordic conditions, as the same models can be applied in other environments. The technology, size and scale of the studied virtual facilities were determined after conversations with industrial experts. The technologies used in the production were well-tested and purchased by real life customers of each machinery manufacturer. Facility capacities were concluded to be of a large industrial scale, which would help further studies in examining entire wood value chains in the future. The majority of industrial wood is delivered to big units capable of handling the production of several harvesters and forwarders from the forest end of the wood supply chain; this was one key factor when forming the technology selection outlines of this study.

Since the costing information of existing companies is generally under strict business secrecy, the data collection of this study was planned accordingly. Most of the data used in the studies were received from consultants, mill managers and other experts, who wished to remain unnamed in the studies; this was brought out in each of the articles. Nevertheless, despite the fact that the data were acquired in an unusual scientific way, the results were thoroughly scrutinized, taking the information source types into account. Other

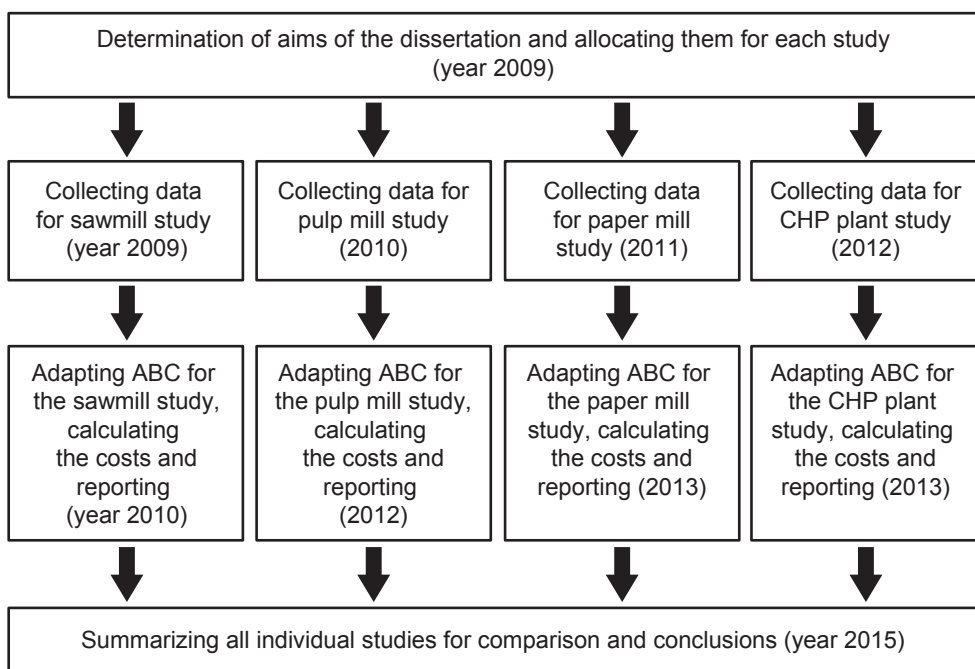


Figure 3. Realization of this dissertation. The year mentioned in parentheses indicates the finishing time of each task.

machinery manufacturers also evaluated the reliability of the production information used in the calculations, since all the processes must operate on the same scale. For example, in the sawmilling study, the capacity of a log debarker that is delivered by one machine manufacturer, must be sufficient for the capacity of sawing and edging machinery delivered by another manufacturer. All the material and used input data were openly presented and peer-reviewed.

The collected material mainly handled the resources of each plant. Machinery and building purchase prices were key elements of the cost calculations. The number of workers both in the production and auxiliary tasks, and electricity and heat consumption of each process were also essential when determining the costs. Additionally, if relevant process-based costing information was available, e.g. established repair and maintenance costs or insurance costs, they were taken into account.

Furthermore, some technical data were collected. For example conveyor speeds and gaps between logs at the sawmill, material flows at the pulp and paper mills, and energy flows at the CHP plant were explored for cost allocations. Detailed information of each costing case is presented in papers I–IV.

Product incomes were collected from public statistics for the profitability analysis. Price information was generally available for all plants apart from the sawmill. The sawmilling profits were not calculated, since product prices vary according to the dimensions, and visual and mechanical strength properties of a product. This information was not available when the cost model was built. Yet, the basic principle of the profit calculation was performed with the sawmilling case similarly than with other cases: the production costs are deducted from the incomes.

2.2 Cost objects: raw materials and products produced by the studied mills

Ceteris paribus was the basic idea of the modelling, and testing the cost structures of each market situation. This means that other factors, e.g. forest policy, taxations, salaries and prices of other than the tested forest products were assumed to be stable or fixed despite the designated changes in the variables of each calculation.

According to the basic principles of ABC, the cost objects must firstly be determined, and secondly the production should be divided into processes for gaining detailed information. This was also the answer to the first main objective of this thesis. The cost objects of papers I–IV were determined uniformly from the forest viewpoint; the wood, as roundwood or woodchips, was the common cost object for each study. The production costs of logs partially determine the willingness to pay for the raw material.

The ABC method additionally enables the cost analysis of other cost objects besides mere raw materials. Attention was paid to the product costs from the end product viewpoint since the profitability of any production plant or mill is determined by the productions and raw material costs and also by the incomes from the end product markets.

After modelling the mills using ABC, which was the primary aim of each paper (I–IV), the secondary aims of the studies were to conduct case studies to test each model using sensitivity tests. The basic idea of the case studies was to test the cost structures of each facility when changes occur in production or in the markets. The studied mills consumed only Norway spruce and Scots pine wood materials. With sawmilling, the case studies tested how production costs change with changing sawing patterns. The amount of sideboards was reduced from case 1 to case 2. This increased the amount of chips and sawdust, as the amount of input logs was the same. The basic density of materials was not a variable in the calculations. In the pulp mill article, the basic density of pinewood was higher (395 kg/m³) with butt logs from thinnings, named case 1, in comparison to the top logs received from clear-cuttings (377 kg/m³), named case 2. Basic density of wood material was different with spruce and the paper mill study when compared to pine: the density (396 kg/m³) in case 2 with thinning wood was lower than the wood received from clear-cutting in case 1 (425 kg/m³). Wood raw material densities and amounts used in papers I–IV are presented in Table 1. The

Table 1. Basic densities (kg/m³) and annual consumption (m³ solid) of wood raw material used in papers I–IV.

		Basic density (kg/m ³)	Raw material consumption (m ³)
Sawmill (I)		–	346 246
Pulp mill (II)	Thinnings	395	4 247 674
	Clear-cuttings	377	4 220 114
Paper mill (III)	Thinnings	396	525 278
	Clear-cuttings	425	495 660
CHP plant (IV) *	Norway spruce	400	207 575
	Scots pine	385	210 816

* 4500-hour utilization rate

key outputs and thus cost objects of the mills were sawn lumber (paper I), bleached softwood kraft pulp (paper II), supercalendered paper (paper III), and heat and power (paper IV). All key outputs are presented in Table 2.

Some substitutive utilization of wood is possible although the uses and raw materials differ. Especially higher quality requirement raw materials, such as saw logs, may be transported to lower quality uses e.g. to pulpwood. The cost correlations in these quality transitions are different between the two end uses and the sensibleness of the action must be denoted. Production costs and profit comparisons are the most practical way to estimate the best use for each wood assortment.

Raw material and end product market prices must also be known for estimating the profits. As indicated earlier, the exact prices of sawn lumber was not available at a detailed level, so the sawmilling study focused solely on production costs. The other plants (papers II–IV) operated on more open markets with limited production assortments and thus market prices were available. In the pulp and paper mill studies, log prices encased stumpage prices, harvesting, forwarding and long distance transportation costs. In the fourth paper, raw material price was paid according to the energy content, and the procurement price additionally covered the costs of chipping. Raw material and end product market prices are presented in Table 3.

Table 2. Key outputs of each studied mill, papers I–IV. (Adt is air-dry tonne, Dt is dry tonne).

		Primary product	Secondary product	Tertiary product	Quaternary product	Quinary product
Sawmill (I)	Case 1	Sawn lumber: 187 546 m ³	Chips and sawdust: 100 502 m ³	Bark: 58 198 m ³	-	-
	Case 2	Sawn lumber: 157 514 m ³	Chips and sawdust: 130 534 m ³			
Pulp mill (II)	Case 1			Bark: 590 427 m ³		
	Case 2	Kraft pulp: 600 000 Adt	Heat and power: 1 723 688 MWh	Bark: 388 250 m ³	Tall oil: 21 000 Dt	Turpentine: 6 000 Dt
Paper mill (III)	Case 1					
	Case 2	Paper: 300 000 Adt	-	-	-	-
CHP plant (IV)*	Case 1					
	Case 2	Heat: 261 000 MWh	Power: 130 500 MWh	-	-	-

* 4500-hour utilization rate

Table 3. Market prices of main products and raw materials used in papers II–IV. (Adt means air-dry tonne).

Market prices of end products and raw materials	Pulp mill (II)		Paper mill (III)		CHP plant (IV)		
Primary product	Pulp: 692 €/Adt		Paper: 590 €/Adt		Heat: 54.52 €/MWh, Electricity: 66.79 €/MWh		
	Thinnings	Clear-cuttings	Thinnings	Clear-cuttings	Norway spruce	Scots pine	Reed canary grass
Primary raw material	41.66 €/m ³	38.94 €/m ³	43.22 €/m ³	38.38 €/m ³	35.86 €/m ³	35.31 €/m ³	62.86 €/t

2.3 Production processes and main cost factors of the plants

The plant production processes in papers I–IV were evaluated with a practical grip: the processes were handled according to a general plant division system. This is beneficial for companies, because the applications presented in the articles are easy to compare with the current costing and accounting systems of similar plants.

Despite the similar raw materials, the economics and productivities of the studied mills varied a lot. Production capacity was set at an economically sustainable level, which meant variation in hardware purchase prices between papers I–IV. Some of the productivity factors were determined by the demand of continuity: e.g. energy production via combustion must run without interruptions, which set separate working hours for some processes. Generally, the high mechanization rate of forest industry causes high capital costs, but the amount of workers was still significant. The prices presented in this synthesis or in the papers do not include a value added tax or governmental subsidies.

2.3.1 Sawmill

The sawmill cost model, presented in paper I, was planned for a large-scale softwood sawmill, where annual production capacity was approximately 200 000 m³ sawn lumber, and all needed production processes are handled within one field. In some cases the sawmills have outsourced certain individual processes, e.g. energy production, which must be taken into account when calculating and allocating the process costs. In the sawmilling model, production was divided into eight production processes with one supportive process. The production processes were log receiving, unloading and sorting; debarking; sawing and edging; green sorting and stickering; drying; quality sorting and packing; storing and shipping; and woodchip and sawdust production. All production processes were directly and mostly involved with sawn lumber production, although the first three processes also served woodchip and sawdust production. A part of these costs were therefore allocated to woodchips and sawdust, which also formed a cost object. The woodchip and sawdust production costs were allocated fully to the woodchips and sawdust. Sawmill management and administration was the supportive process, the costs of which were allocated to all other processes. Ground construction costs were also taken into account when allocating the costs to all processes. The processes of the modelled sawmill are presented in Figure 4.

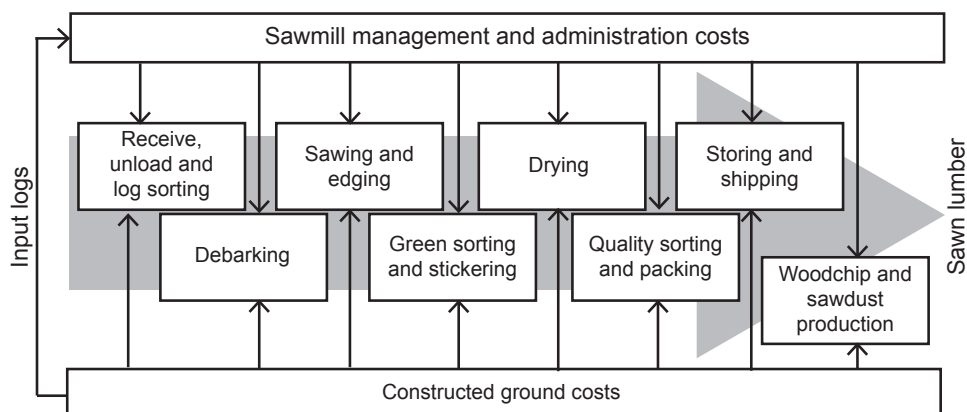


Figure 4. Description of the sawmilling processes, material flow (large arrow) and indirect cost allocations (small arrows).

After process definition, the required resource information for the cost calculations was collected. The key cost factors of sawmilling production processes are presented in Table 4. The production processes consume resources and thus cause costs. The wood is transported through the processes as logs, sawn lumber and also as wood chip residue that require investments in machinery and buildings. Flowing activities require e.g. conveyers, debarkers, saw machines, sorters, dryers and packers. These investments cause capital costs that must be taken into account as part of the production costs. The depreciation time varied from 10 (machinery) to 30 years (buildings). Heat and electricity are also key cost elements in sawmilling production. Although heat is often produced in a plant's separate heating plant by burning bark, both heat and electricity were also bought from external providers. Process

Table 4. Key production cost factors of the studied sawmill.

Cost factor	Value	Unit
Price of buildings and machinery	28	million €
Interest rate	5	%
Production hours in a day	8 (16*)	h
Production days in a year	238 (330*)	d
Electricity consumption	12 618 836	kWh/year
Process heat net consumption	47 824 266	kWh/year
Electricity price	0.0722	€/kWh
Heat energy price	0.03	€/kWh
Process managers (during one shift)	6	persons
Labour cost of a manager	34	€/h
Process workers (during one shift)	17	persons
Labour cost of a worker	25.5	€/h

* drying process

workers, though crucial for sawmills, also cause labour costs via direct and indirect wages. It is noteworthy that the continuous drying process requires more labour efforts than other production processes. Detailed and process-allocated factors are presented in paper I.

2.3.2 Pulp mill

The pulp mill study (paper II) concentrated on a large-scale (annual production capacity 600 000 air-dry tonnes) kraft pulp mill that produces bleached softwood market pulp in Nordic conditions. The production was divided into ten actual production processes and similarly to the sawmilling case, the mill management and administration was a separate, supporting process. The processes were receiving, unloading and debarking of logs; chipping; chip screening; chip storing; cooking; pulp washing; pulp screening; delignification and bleaching; and pulp drying and finishing. The chemical recovery process, where green liquor is burned and recausticized for pulp cooking, was also considered a separate production process. The pulp mill model handled more cost objects than the sawmill model. The objects were pulpwood logs, market pulp, energy fragment (from black liquor burning), bark, tall oil, and turpentine. The processes of a pulp mill are presented in Figure 5.

Processes require machinery, which consists of e.g. conveyers, rum debarkers, chippers, screeners, cookers, washers and dryers. The pulp mill had the highest machinery and building prices of all the studied plants, obviously affecting the capital costs. The pulping processes are continuous and thus the production is running full-time with only few yearly stoppages. The employees work in three shifts, which must be taken into account in the labour costs. Pulping is a very energy-intensive industry and the production requires vast amounts of both heat and electricity. Yet, the mill is practically self-sufficient with regards to energy, because the lignin and wood residues in black liquor can be burned and converted into heat and electricity. The surplus energy can be sold outside of the mill, reducing production costs. The key production factors of the pulp mill study with the clear-cutting raw material case are presented in Table 5.

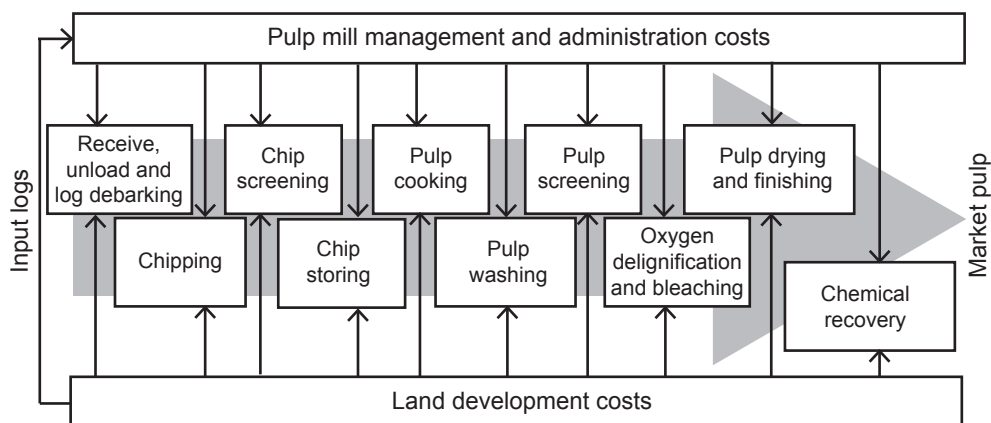


Figure 5. Description of the pulp mill processes, material flow (large arrow) and indirect cost allocations (small arrows).

Table 5. Key production cost factors of a pulp mill in the clear-cutting raw material case.

Cost factor	Value	Unit
Price of buildings and machinery	658.2	million €
Interest rate	5	%
Production hours in a day	24	h
Production days in a year	357	d
Electricity production	631 680	MWh/year
Electricity consumption	328 257	MWh/year
Process heat net production	2 523 333	MWh/year
Process heat net consumption	1 103 068	MWh/year
Electricity price	40.8	€/MWh
Heat energy price	30.0	€/MWh
Process managers (during one shift)	7.5	persons
Labour cost of a manager	42.5	€/h
Process workers (during one shift)	18.5	persons
Labour cost of a worker	34	€/h

2.3.3 Paper mill

The paper mill study (paper III), described and modelled a mill that produces supercalendered uncoated magazine paper, with an annual production capacity of 300 000 air-dry tonnes. The production consisted of ten processes: receiving, unloading and log debarking; TMP (thermo-mechanical pulping) mill; stock preparation; headbox and former; press section; dryer; reeler; calendar; winder; and roll storage. The administration and management is a separate, supporting process. In comparison to papers I and II, the ground construction or development costs were not considered separate cost factors, but were included in the building and machinery prices. This was due to practical reasons: the machinery and buildings are sometimes purchased as turnkey delivery, which includes all needed constructions, so a separate cost factor was not needed.

The cost objects of the studied paper mill were paper, logs with and without bark, kraft pulp, fillers, chemicals and bark (as a separate product). The processes of a paper mill are presented in Figure 6.

The pulp milling case required the most investment capital in our studies I–IV, followed by papermaking. A variety of machinery is needed in production since the wood is conveyed, debarked, and processed as logs, chips, wet pulp and in paper form throughout the mill. In contrast to the other studies (papers I, II and IV), the machinery and buildings also caused repair and maintenance costs that were taken into consideration alongside the capital costs. The paper mill runs 24 hours a day almost throughout the year, so employment-related costs are also important. The TMP process generates surplus heat that can be taken into account as profit. Required electricity must be bought from outside the mill. The cost factors of the paper mill are presented in Table 6.

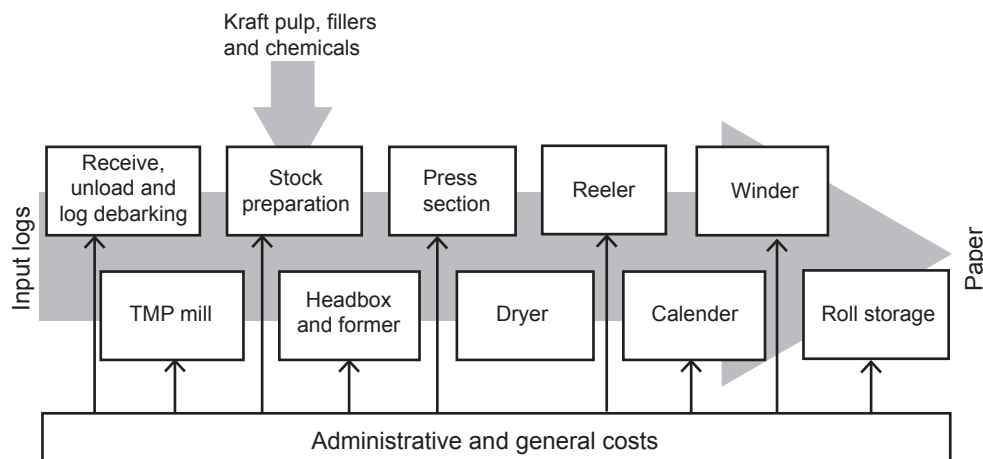


Figure 6. Description of production processes of a TMP-based paper mill. Material flow (two grey arrows) and indirect cost allocations (small arrows).

Table 6. Key cost factors of the paper mill study.

Cost factor	Value	Unit
Price of buildings and machinery	296	million €
Interest rate	5	%
Production hours in a day	24	h
Production days in a year	357	d
Electricity consumption	3 334	kWh/Adt
Process heat net production	1 527	kWh/Adt
Process heat net consumption	1 096	kWh/Adt
Electricity price	0.041	€/kWh
Heat energy price	0.030	€/kWh
Process managers (during one shift)	3.5	persons
Labour cost of a manager	42.5	€/h
Process workers (during one shift)	28	persons
Labour cost of a worker	34	€/h
Repair and maintenance costs	956 715	€/year

2.3.4 Combined heat and power plant

Paper IV, which modeled a large-scale CHP plant, focused on key issues concerning wood-based energy production. The maximum annual net heat and electricity production were 290 GWh and 145 GWh, respectively. The cost objects were wood (as chips), reed canary grass (*Phalaris arundinacea*), heat energy and electricity. The production was divided into four processes: fuel handling, a fluidized bed boiler, a turbine plant and flue gas cleaning. The

administration was also taken into account as a supportive department, the costs of which were allocated to the production processes as in papers I–III. The fuel-handling process included fuel unloading and storing of the wood raw material and reed canary grass, which was an additional fuel source. The wood was received as chips, and the reed canary grass, which was studied as a minority fuel, was also ready for use. The fluidized bed boiler consisted of fuel and sand feeding systems that served the actual boiler, where the burning took place. The turbine plant fully served the electricity production. Flue gas cleaning was also considered a separate production process, where an electrostatic precipitator was used for removing fine particles from the exiting gas. Costs from district heat piping were not included in the study. Ash was ignored in the study because of its small amount, which was considered to be 0.5% of the dry fuel mass. The CHP plant processes are presented in Figure 7.

The machinery of the CHP plant differs from the previous studies (papers I–III) in the sense that at the beginning of processes the wood raw material is not handled as logs but as chips. The chips are stored and eventually transported to the boiler via conveyors. Energy is transported with pumps and pipelines inside the plant and also transformed into electricity. The machinery and buildings formed a significant cost factor via the capital costs. The plant operated full-time throughout the year since the energy demand was considered to be continuous. Energy production intensity was handled with the utilization rate, which indicates the time of the combustion process. The utilization time was tested with three cases and the interest rate was also considered to vary. These factors affect the energy production and capital costs, respectively. This study also considered the annual insurance expenditures as one cost factor. The key cost factors of the CHP plant are presented in Table 7.

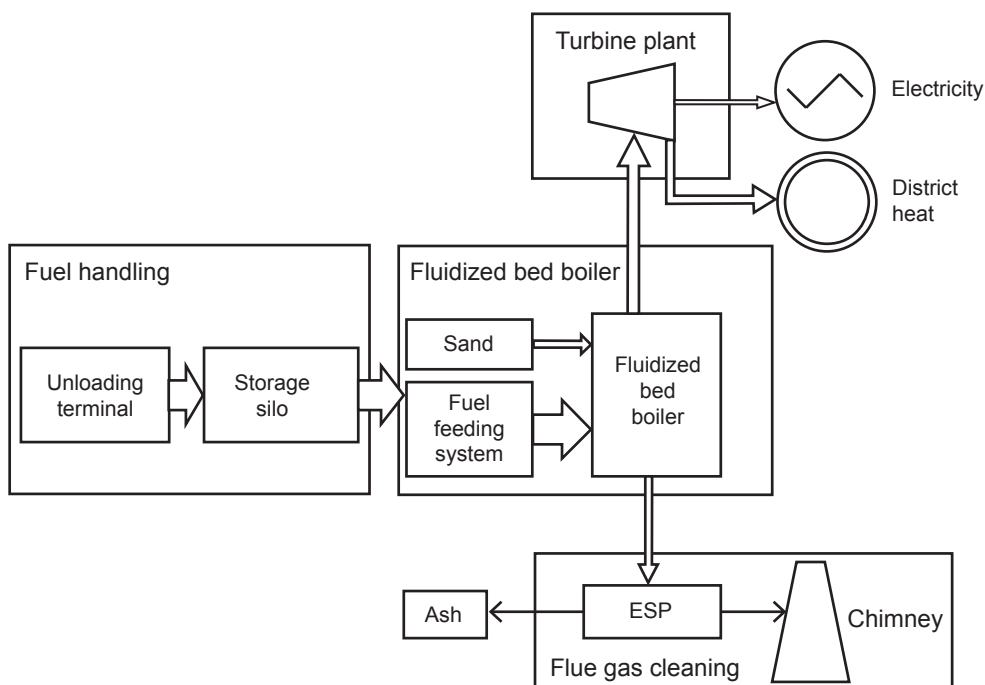


Figure 7. Description of the production processes in a CHP plant. Wide arrows represent material or energy flows such as screw or belt conveyors and pipelines.

Table 7. Key production cost factors of the CHP plant.

Cost factor	Value	Unit
Price of buildings and machinery	59.45	million €
Interest rate	3–10	%
Production hours in a day	24	h
Production days in a year	365	d
Utilization rate	4 000; 4 500; 5 000	h
Process managers (during one shift)	4	persons
Labour cost of a manager	42.5	€/h
Process workers (during one shift)	11	persons
Labour cost of a worker	34	€/h
Annual insurance costs	596 080	€/year

2.4 Cost modelling

Although the ABC method does not require costs to be divided into fixed and variable, the cost factors were classified according to these traditional cost classes. Cost modelling consists of both economic and engineering areas. The economic part handles the general and process-based cost calculations, while engineering mainly covers the tools for allocating costs to the processes and products.

As the basic principle of ABC states, activities consume resources that cause costs. All processes have some common cost factors: machinery, buildings and constructed ground cause interest costs and their value decreases annually. This has to be taken into account as capital costs in relevant processes. The capital cost calculation is partly controlled by national legislation, so the following method is directional. The capital recovery charge method (Liebster and Horner 1989; Mani et al. 2006) was used in papers I–IV. The annual capital cost is calculated using the following equation:

$$AC_{\text{capital}_t} = PP_t * \left[\frac{I * (1 + I)^{SL_y}}{(1 + I)^{SL_y} - 1} \right] \quad [1]$$

where:

AC_{capital_t}	Annual capital cost for a object t, € or \$/a
PP_t	Purchase price of object t, € or \$
SL_y	Service life in years, a
I	Interest rate, in decimal form

Despite the fact that forest industry is highly mechanized, most industrial production processes need workers and this causes labour costs. Labour costs are formed from direct hourly wages and indirect wage costs. Indirect wage costs consist of pension contributions and other social costs paid by the employer. Most administrative costs were labour costs, and

the costs were calculated in a similar manner as for the process workers. Annual labour costs per person were calculated in papers I–IV using Equation 2.

$$AC_{\text{lab}_p} = WH * WC + \left(WH * WC * \frac{IWC}{100} \right) \quad [2]$$

where:

AC_{lab_p}	Annual labour costs per person p, € or \$/a
WH	Working hours, h/a
WC	Wage cost, € or \$/h
IWC	Indirect wage costs, %

Heavy ground constructions, with proper draining systems, ground frost insulations and gravel surfaces are needed for successful large-scale plants. The ground construction costs can be calculated as a separate cost, with its own annual depreciation (used in papers I and II) or ground construction costs can be taken into account in the purchase prices of buildings (in papers III and IV). The costs can be considered as supporting infrastructure for the building of production processes. Similarly to capital cost, the depreciation times of buildings and ground construction may differ according to national legislations, but the overall costs must nevertheless be considered and allocated to production. The ground construction costs ($AC_{\text{gr}_\text{cost}}$), including interest cost, were calculated as follows:

$$AC_{\text{gr}_\text{cost}} = A * C_{\text{gr}_\text{const}} * \left[\frac{I * (1 + I)^{SL_y}}{(1 + I)^{SL_y} - 1} \right] \quad [3]$$

where:

$AC_{\text{gr}_\text{const}}$	Annual costs from ground construction, € or \$/a
A	Area of a mill, ha
$C_{\text{gr}_\text{const}}$	Ground moving costs, € or \$/ha
SL_y	Service life in years, a
I	Interest rate, in decimal form

One important cost factor is the wheel loader or forklifter, which is used for transporting materials from one process to another. Costs from the loading machinery are allocated to each relevant process that consumes the resource. The loader costs were calculated using following equation:

$$AC_{\text{loader}} = WH * HC_{\text{loader}} \quad [4]$$

where:

AC_{loader}	Annual costs of wheel loader, € or \$/year
WH	Working hours, h/a
HC_{loader}	Hourly costs of wheel loader, € or \$/h

Heat and electricity are important factors in forest industry. Energy prices vary and determine many strategic decisions such as which process heat source is most beneficial,

and what is the most efficient logistic chain for a product. The annual electricity costs were calculated using Equation 5.

$$AC_{\text{electricity}_r} = OH_r * \frac{(P_{\text{electricity}} * E_{\text{nominal}_r} * E_{\text{load_factor}_r})}{100} \quad [5]$$

where:

$AC_{\text{electricity}_r}$	Annual cost of electricity for process r, € or \$/year
OH_r	Annual operating hours in process r, h
$P_{\text{electricity}}$	Price of electricity, € or \$/kWh
E_{nominal_r}	Electricity wattage in process r, kW
$E_{\text{load_factor}_r}$	Net load factor of electricity consumption in process r, %

Some processes consume heat energy produced at the mill. The heat energy has an alternative cost, which is considered a cost factor and was calculated in the following way:

$$AC_{\text{heat}_r} = P_{\text{heat}} * E_{\text{heat}_r} * \text{Prod}_{\text{tot}} \quad [6]$$

where:

AC_{heat_r}	Annual cost of heat energy for process r, € or \$/year
P_{heat}	Price of heat, € or \$/MWh
E_{heat_r}	Heat energy consumption per produced pulp in process r, MWh/tonne
Prod_{tot}	Total annual pulp production, tonnes/year

Each equation may be used for each process more than once, e.g. different machinery used in the same process may have different depreciation times, meaning that the capital costs must be calculated separately for each factor. When all annual cost factors are modelled and calculated for a studied process, the costs can be summed for allocating the cost objects of the process.

2.5 Cost allocation: From cost drivers to unit costs

Despite the cost factors being calculated somewhat equally, the costs were allocated to the cost objects in different ways. The main idea of the cost allocation and driver selection was to describe the resource consumption while processing the cost objects in a process.

In paper I, the costs were allocated to products according to lead time. Lead time was determined by the nominal speeds of conveyors used at a sawmill. Lead time was dependent on the processing time of each product or product group. The use of lead time as a cost driver was favoured because most of the variable costs, e.g. electricity costs, are caused by electric motors during the processing and conveying of the products through the process. The motors are work on the cost object for that current lead time, consuming electricity and thus incurring costs.

Cost drivers for the non-bulk products in the pulp, paper and energy productions (papers II–IV), were dependent on the mass or energy flows of the cost objects. Material flows were determined for each process in a similar way as in the sawmilling study: material or energy delivery further on in each relevant process consumes the production resources and was thus

considered to be the premise for cost allocation. The material losses of the cost objects were also taken into account in papers II and III.

Finally, when all process costs of each cost object were calculated and allocated, the unit cost of the objects was summed to compile complete cost estimations that fulfill the second aim of the thesis.

3 RESULTS OF THE COST AND PROFIT STUDIES

Each paper (I–IV) focused on one individual mill production. The test results were calculated using spreadsheet programmes designed for each study. The key results of the studies concentrated on the production costs of the mills. It is noteworthy that the costs and profits were ad hoc and thus the generalization of the results must be handled with certain caution. Annual production costs varied according to the size of the studied case. The total annual production costs of the sawmill (1) were slightly over 7 million Euros. The pulp mill (2) functioned with 216 million Euros. The paper mill (3) operated with 88 million Euros and the CHP plant (4) with 11 million Euros (5% interest rate). The studies also handled other cost objects than the key ones presented in this synthesis, e.g. chemicals and fillers in the paper mill, which are dealt with in detail in papers I–IV.

3.1 Costs

The cost structures of the studies revealed that energy intensive processes are apparently the most costly aspects of production. The drying of sawn lumber caused approximately 40% of all the production costs at the sawmill (I). With the pulp mill case (paper II), the pulp drying process (18.6%) had the second highest production costs, after the chemical recovery process (39%). Paper drying caused 18% of the costs at the studied paper mill (III), being the second most costly process after the TMP process (35%). The highest share of the CHP plant (IV) production costs was the fluidized bed boiler, 46.6% (with 4500-hour utilization and a 5% interest rates). Contrary to other studies, no drying process was involved in the energy production. Three processes with the highest share of production costs of each study (papers I–IV) are presented in Figure 8.

Production costs allocated to the raw materials were possibly the most important results for the wood value chains from the forest-end viewpoint: the difference between wood procurement prices and wood raw material production costs essentially creates the profitability of the wood value chains from the forestry viewpoint. The unit production costs of sawmilling logs were strongly dependent on the volume of logs and the sawing pattern; the largest logs had the lowest production costs. The decrement of lumber pieces (from case 1 to case 2) reduced the unit costs of sawing in same log classes. The unit production costs of sawmilling for logs are presented in Table 8.

Similarly to the production costs of raw materials, the production costs of end products help in determining the profitability of the value chains from the forest industry to the markets and end users. When calculating the costs of sawn lumber in the reference case (case 1), the smallest boards caused the highest unit production costs (40.59 €/m³), as the lowest production costs (30.41 €/m³) were achieved with larger centerpieces. When reducing the number of lumber pieces programmed into the sawing patterns (case 2), the costs of

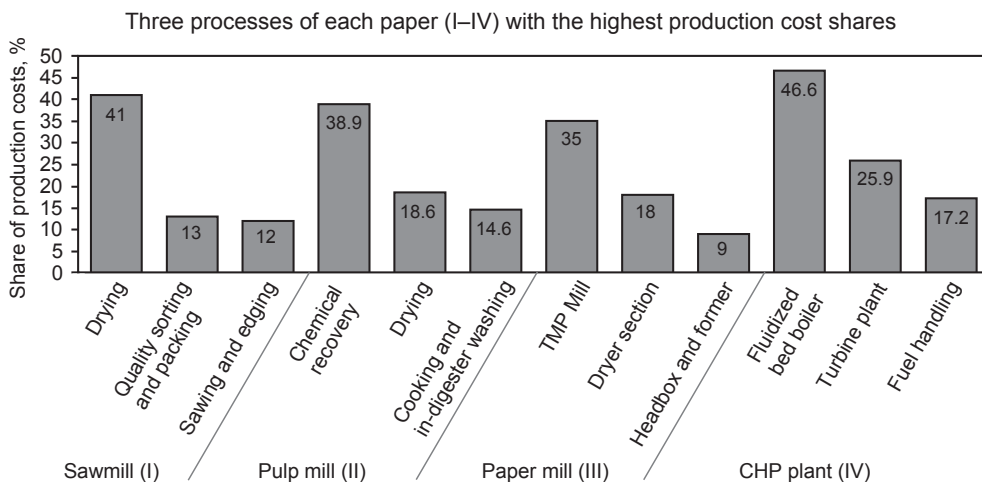


Figure 8. Three highest shares of production costs in the saw-, pulp and paper mills and the CHP plant.

Table 8. Production costs of the sawmill case studies 1 and 2 per roundwood cubic metre, €/m³ according to log small end diameter and length classes. The amount of sideboards was reduced from case 1 to case 2.

Small end diameter class (cm)	Log length class (m)							
	4.0		4.3		4.6		4.9	
	CASE 1	CASE 2	CASE 1	CASE 2	CASE 1	CASE 2	CASE 1	CASE 2
17	25.11	23.65	24.64	23.21	24.23	22.83	23.87	22.50
19	22.37	21.12	21.99	20.76	21.65	20.45	21.36	20.18
21	22.11	21.67	21.69	21.23	21.32	20.85	21.00	20.52
23	20.53	19.64	20.18	19.28	19.87	18.96	19.60	18.67

individual logs were higher with the same log classes. The production costs for sawn lumber are presented in Table 9.

The test calculations in papers II–IV were simpler in comparison to the sawmilling study, as the raw material and end product distributions were more limited. The costs were calculated for pulp and paper production with logs procured from thinning and clear-cutting. Furthermore, the CHP plant study handled simple fuel combinations of wood and reed canary grass.

With the pulp and paper mill studies, log production costs did not vary significantly between the thinning and clear-cutting cases. The so-called side product costs were also calculated in the pulp mill calculations: the cost of energy fragment produced alongside pulp was 119 €/dry tonne (Dt, in paper II also referred to as moisture-free tonne, m.-f. tonne), while the costs incurred from tall oil production, bark handling and turpentine production were 2.79 €/Dt, 0,35–0,50 €/Dt, 0,17 €/Dt, respectively.

With the CHP plant cases, the production costs allocated to heat were approximately 23.96 €/MWh and to electricity 49.50 €/MWh with a 4000-hour annual utilization rate and a 5% interest rate. The utilization time increment decreased the unit costs. With a 4500-hour utilization rate the heat and electricity costs were 21.30 €/MWh and 44 €/MWh, respectively. In the third test, with a 5000-hour utilization rate, the heat and electricity costs were 19.17 €/MWh and 39.60 €/MWh, respectively. The production costs of the pulp and paper mills and the CHP plant main products and main raw materials are presented in Table 10.

Table 9. Production costs of sawn lumber according to the log and lumber dimensions. The amount of sideboards was reduced from Case 1 to Case 2.

Log small end diameter class (cm)	Centerpieces			Boards					
	Thick- ness (mm)	Width (mm)	€/m ³	Thick- ness (mm)	Width (mm)	€/m ³	Thick- ness (mm)	Width (mm)	€/m ³
CASE 1									
17	50	100	35.59	19	100	40.01			
19	50	125	32.93	19	100	37.52			
21	50	150	31.96	19	100	36.83			
23	50	150	30.41	19	125	34.04	19	100	40.59
CASE 2									
17	50	100	38.78	19	100	48.96			
19	50	125	35.68	19	100	46.03			
21	50	150	34.53	19	100	44.52			
23	50	150	32.88	19	125	39.66	19	100	47.58

Table 10. Production costs of the pulp and paper mills and the CHP plant calculated for both the main raw materials and the main end products of each mill.

	Pulp mill (II)		Paper mill (III)		CHP plant (IV) *		
	Thinnings	Clear- cuttings	Thinnings	Clear- cuttings	Norway spruce	Scots pine	Reed canary crass
Production cost of main products	Pulp: 133.76 €/Adt	Pulp: 133.87 €/Adt	Paper: 294.33 €/Adt	Paper: 294.33 €/Adt	Heat: 22.97 €/MWh, Electricity: 47.28 €/MWh		
Production cost of main raw materials	50.86 €/m ³	51.2 €/m ³	122.88 €/m ³	131.06 €/m ³	49.00 €/m ³	48.25 €/m ³	78.93 €/t

* utilization rate 4500 hours, 5% interest rate

3.2 Profits

The production profits for the key products and raw materials were calculated in the case studies of papers II–IV. The profit calculations were conducted so as to fulfill the third main object of this thesis. The profits in the pulp mill case were positive throughout the tested cost objects. Similarly, the papermaking profits in the paper mill case study were also positive for both paper and logs in both tested cases. The CHP plant model produced more variation in profitability; electricity production was generally less profitable compared to heat production. Also, with higher interest rates, the profits were lower at the CHP plant. The same effect was also noticed with a decreasing utilization rate. The key profits of papers II, III and IV are presented in Table 11.

Table 11. Key profits from papers II–IV. (Adt is air-dry tonne).

	Pulp mill (II)		Paper mill (III)		CHP plant (IV) *		
	Thinnings	Clear-cuttings	Thinnings	Clear-cuttings	Norway spruce	Scots pine	Reed canary crass
Net profit for primary product	Pulp: 269 €/Adt	Pulp: 294 €/Adt	Paper: 92 €/Adt	Paper: 104 €/Adt	Heat: 11.9 €/MWh, Electricity: -4.3 €/MWh		
Net profit for primary raw material	37 €/m ³	42 €/m ³	53 €/m ³	63 €/m ³	11 €/m ³	11 €/m ³	13 €/t

* utilization rate 4500 hours, 5% interest rate

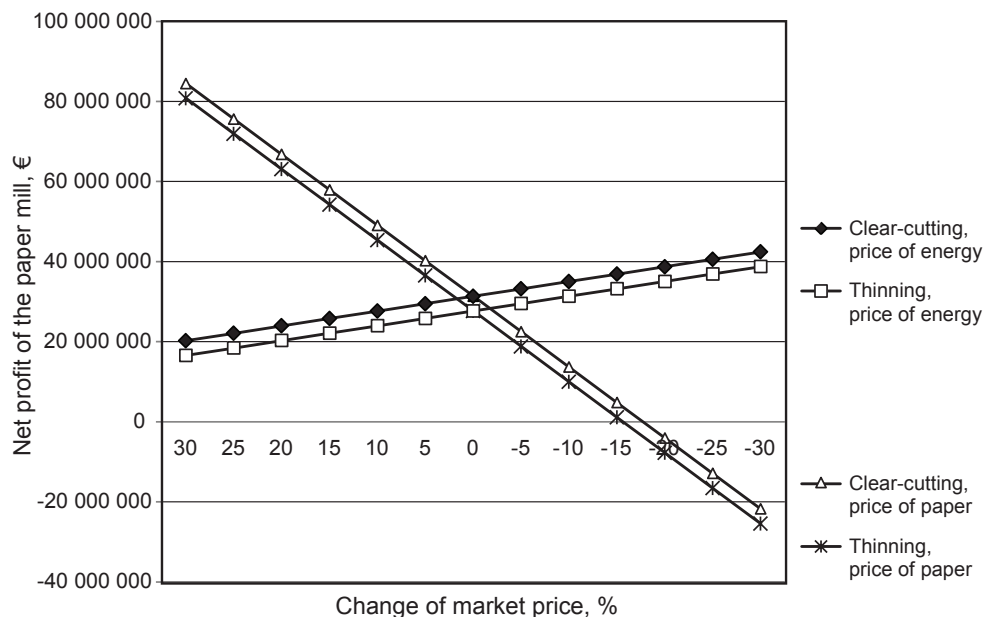


Figure 9. Energy and paper market price effects on the net profit of a paper mill. Point 0% expresses the basic market situation.

A sensitivity test was additionally carried out in the paper mill study with the market prices of energy (both heat and electricity) and paper. This test was conducted to investigate which market price has a greater effect on the annual profit of a paper mill. This test was also conducted with the abovementioned *ceteris paribus* assumption when the market price of either factors was lowered to -30% and elevated to +30% compared to the basic market situation. The results of the sensitivity analysis are presented in Figure 9.

4 DISCUSSION

Thorough cost estimations are worthwhile for any investor, since global competition is heartless and searching for the best possible investment value is continuous. According to the results, the ABC method was flexible enough to fit within the demanding environment of the forest industry: the production and costs of the saw-, pulp and paper mills and the CHP plant were successfully modelled. The decision-making research paradigm appeared to be functional for the purposes of this study. The supply chain management of the forest industry will also have accurate information for making more profitable decisions. The test calculations with the models indicated that ABC can deliver useful information not only for investors but also for industrial engineering and management. Since ABC was successfully adapted to each of the four plants, tested with the virtual cost calculations and the profits of the pulp and paper industry and the energy production were calculated, the first three aims of the study were achieved. The fourth main aim of this study, evaluating the results from the forestry viewpoint, is handled as a whole in the following discussion chapter.

4.1 Applicability of the results

The activity-based costing method proved useful in several ways. Firstly, the process-based approach of the ABC is well-suited for preparing the cost estimates of the virtual plants and mills; individual parts and processes can be estimated separately and the best possible combination of production factors can be easily found. This finding is parallel with Hsu and Hsu (2008). Mills are nowadays purchased and delivered by several machinery producers, thus the estimation of the best possible combinations must be prepared as thoroughly as possible. From this viewpoint ABC appears almost invincible. The costing information received by the ABC is detailed and can also help to pinpoint any production bottlenecks.

The results of this study can help plant managers estimate how implementing changes may affect either a single process or the entire production. For example reducing the amount of sideboards in the sawmilling changed not only the production costs but also increased the amount of wood chips produced, which must be taken into account when planning chip delivery to pulp or paper mills. On the other hand employees at all levels of the CHP plant will surely benefit from information indicating the correlation between the utilization rate and production profits. Furthermore, process-based models are easy to update if e.g. some machinery is changed, as the modification has only to be made for those processes that the technological update deals with.

The ABC models can be used for developing SCM. The SCM manager can evaluate different supply chains and compare them with each other using the virtual models. A few calculations can be used to find the most profitable route for a product or raw material. The

costing information received from the models can be included into current SCM models for real-time calculations and actual cost information. The results of this study can also be used for either inventing new or improving current practices: by making comprehensive cost structures for the blueprints of novel products or services may assist in finding the most profitable way of executing different tasks.

Cost driver selection is one key aspect when estimating result success. In papers I–IV, the drivers focused on the products: the essential cost drivers in paper I were the lead times for handling the products, in papers II and III the drivers were the mass flows of production, and in paper IV the drivers were determined by energy flows throughout each process. The use of lead times as cost drivers in paper I and the material as well as energy flows in papers II–IV were practical and described well the resource consumption of the production in industrial-sized mills. For example, most of the electricity consumption in the industry is caused by electric motors (in conveyors, pumps, fans, etc.) and according to a survey (Saidur 2010) the efficiency of an electric motor is not significantly affected by the load, if the size of the motor is appropriate. This means that e.g. the size of an object transported on a conveyer belt does not describe the electricity consumption as well as the time that the resource is being used. Lead times and material flows are also relatively easy to identify using a time and productivity study. The drivers in the studies were selected to represent the most basic elements of production. Still, according to Turney (2005), the drivers must always be set according to cost calculation purposes. If the driving force of establishing a new costing method is e.g. to study the cost structures of a client service, the drivers must be set to describe the resource consumption of each customer to achieve relevant costing information. Obviously, whichever costing method is used, the benefits of the selected method must be expected to be cost-effective: a method requiring more efforts than the results can deliver is useless.

Although using virtual mills was unavoidable because business secrecies prohibited the use of real life cost and production data, the applications were tested using the virtual plant concept. However, no significant reasons were found why the models could not be applied also to existing plants instead of virtual greenfield models with applicable cost factors.

A human factor is always involved when applying new costing methods. Shanahan (1995) noted that the workers of companies that are reconstructing and detailing their costing systems are suspicious about the agendas of such transitions. System modernization is undoubtedly supposed to help company management gain profits from unprofitable divisions, which may cause workforce cutbacks. However, system modernization and pinpointing of productivity gaps may help workers concentrate on more economical tasks that will consolidate the employer's market position. It is important that management clearly indicates the reasons behind these changes, so as to dismiss any misgivings felt by the employees.

This study did not handle the costs of implementing a new costing method. Malmi (1999) indicated that ABC is expensive because data collection and the start-up phase for full utilization require great efforts and knowledge. It is clear that a company willing to adopt ABC for the first time must either purchase the education, knowledge and applications from an outside service provider and/or recruit sufficient personnel for the task. These actions will cause costs. When comparing the requirements for this detailed ABC method with more simplified plant- or department-level cost modelling, the benefits of the new method must be considerable.

4.2 Adapting the ABC for forest industry

Generally, the ABC method was easy to adapt to industrial-sized plants and mills. This was mostly due to the traditions of process definitions: all branches of industry had established fairly clear production processes. Machinery manufacturers are important information sources as they have been forced to adapt their actions according to the process definitions of production plants, so as to be able to cover one or several of the production processes in their businesses. On the other hand, the industry or clients have benefitted from this tradition by gaining clarity and unambiguity in their orders when new plants or machinery updates are being planned.

Moreover, the ABC method was relatively easy to assimilate into the industrial sawmill. The process definition of the sawmill in paper I was well-suited for both the study purpose and generally for estimating sawing costs. The process definition followed a fairly widespread characterization of sawmilling and most of the machinery manufacturers currently use similar detailing in their businesses. The capital costs derived from machinery were thus easy to pinpoint to a relevant process and no overlapping occurred between the processes. The processing was designed for full profiling machinery, where the log passes only once through the conveyor and is simultaneously sawn and edged. However, if the machinery had been different and e.g. additional resawing would have occurred, the process definition would have required at least one additional cost driver. This additional driver would describe the resource consumption of delivering the cant back to the sawing phase. Some of the processes described in the study are left out of production in certain cases, e.g. drying can be postponed, when the process must be bypassed in calculations or deleted from the equations.

Just as in paper I, the ABC was well-suited to the pulp and paper industry (papers II and III). The pulp and paper industry is more capital-oriented than sawmilling, and annual capital costs are easy to allocate accurately to processes when using the ABC. This accuracy is essential for correct cost structure analysis. The process definitions were linear and quite unambiguous. The CHP study (paper IV) was no different to papers I–III regarding the applicability of the ABC method; cost calculations were relatively easy to conduct and the processes were clearly determined.

4.3 Cost and profit evaluation

The validity and reliability of the absolute costing results from the studies is difficult to verify because public reference results are not available. However, cost model and costing level performances can be evaluated to some extent by assessing the changes between the case studies within each paper. Input information as well as the cost and productivity factors were also initially derived from actual industry, statistics and professionals working in relevant fields of industry. This means that the data were at least directional and thus useful for evaluating the effectiveness of the models. Results of studies I to IV are generally on the same level with other studies handling forest industry. For example the study by Sathre and Gustavsson (2009) illustrated the economic benefits gained by integration in the forest industry: the pulp and paper industry will gain more value-adding by combining some parts of their production. This was the first result obtained in the study by Lantz (2005), and the second result specified that the production scale is the most beneficial investment target. According to the results of this study, investment targets are possible, and are easier to find using ABC.

Costs in the sawmilling study (paper I) varied logically between cases 1 and 2; the sideboard decrement caused higher chip and sawdust production costs and also reduced the drying costs. The results of this study were also supported by Hakala's study (1992), where the unit production cost of logs is inversely proportional to log size. Moreover, results of the sawmill costing in this study were parallel with the observations made by both Rappold (2006) and Tunes et al. (2008), who noted that unbiased cost allocation of the cost objects is the foundation of correct product pricing. Notice must be paid to marginal products in such a highly competitive business as sawmilling, where even small mistakes on minor production fragments may cause a lower earning capacity. The sawmilling study was the only article not directly handling the profitability of the industry.

In the pulp milling study (paper II), changing the raw material from thinning butt logs to clear-cutting top logs did not cause significant variation in total production costs. However, the cost model revealed the effect of bark content on costs the larger amount of bark logically caused higher debarking costs. Furthermore, when considering the entire supply chain from the stump to the pulp mill, the total costs of the thinning pulp logs were slightly higher. Profits gained from pulping were also high according to the cost model, which was partially caused by the beneficial pulp market prices.

The paper mill study (paper III) results did not differ much from the pulp mill. The differences between the thinning and clear-cutting cases were small, and the variation in bark amounts also caused higher processing costs for the clear-cutting of logs. An additional sensitivity analysis on the energy (heat and electricity) purchase prices at the paper mill endorsed the cost model; a clear correlation was found between energy price and production costs. Likewise to the pulping profits, papermaking was also found very profitable according to the models. This was also due to the high market prices of paper. The sensitivity test furthermore revealed that the market price of paper was the most significant variable determining profitability.

Sathre and Gustavsson (2009) implied that the pulp and paper industry will benefit from integration and energy production seems to be the most beneficial and also most studied production factor. As Fogelholm and Bescherer (2006) pointed out, productivity and thus profitability improvements in the pulp and paper industry begin with finding the weak spots in production. The ABC is a very useful tool for this.

With the CHP study (paper IV), the interest rate test acted as assumed; the rate increment raised the total production costs and assumedly lowered the profits. The model also revealed that the utilization rate of the CHP plant has a significant positive influence on profitability. The ABC model also delivered information of the relations between heat and electricity production: heat production was found to be clearly more profitable with all the tested interest and utilization rates. This was believed to be caused by the special treatment process, the turbine plant, which is solely needed for electricity production. The study presented results indicating that the utilization rate correlates with profitability, which was also observed by Wei et al. (2011).

A clearly noteworthy result from the first three papers was the high relative share of drying costs. The process-based aspect of the ABC clarified the significance of the energy economics of all three mills. Water removal is obviously a crucial aspect of production and according to the results the potential for reducing costs is highest among the drying processes. However, the main costs are fixed, as is the amount of energy required for water evaporation. As

mentioned above, several pulp and paper industry studies have focused on energy production optimization (e.g. Frei et al. 2006; Gale 2006; Thollander and Ottoson 2008; Gaudreault et al. 2010; Marshman et al. 2010; Ahmadi et al. 2012). According to the high energy demand of the forest industry, the focus on improving energy efficiency seems to be a relevant path. No separate drying processes were involved in the studied CHP plant, which comprehensively handled energy production. However, modern energy plants have fuel pre-drying systems for improving the energy efficiency of burning biofuels (Spets and Ahtila 2002). One reason for the integration of pulp and paper mills can be explained with energy savings: the slurry from the pulp mill can be pumped directly to a paper mill, thus avoiding the costly drying. Surplus heat from the pulp mill can also be utilized in papermaking.

4.4 Effect on the supply chain management of forest industry

A thorough analysis of wood supply chains requires information from other links of the chains, where the wood is procured and allocated to the use of forest industry. With help from the results presented in this study, the costs or value-addings of one link (product production) of the value chain are known. The other links of the chain were not directly handled in this study, but a cursory survey of the subject can be presented.

The results of this study can be combined with previous studies (Nurminen et al. 2006, 2009) that concentrate on timber harvesting, forwarding and long-distance transportation to re-examine the supply chains of forest industry. Tools now exist in the model combinations for estimating the absolute economic values of each tree bucking decision from the forest to the final products. The wood flows could be routed according to the highest values calculated according to the end product market situations, distances from the logging sites to the mills, and to the tree stem properties at each site.

Wood allocation according to the highest net value without any restrictions in open markets may lead to extreme situations where some logging sites are not economically feasible for harvesting or only one or two timber assortments reach a satisfactory level. Wood flows of entire areas could be turned faster than currently according to market fluctuations. However, testing this type of new paradigm will require wider and more detailed tests to gain accurate results.

Benefits of the suggested market-based supply chain management would be apparent for the entire value chain; achieving the highest net value would, at least in theory, generate more wealth for each link of the supply chains, including forest owners. Present business practices of Finnish forestry do not yet fully enable this novel method. Timber trade agreements between the industry and forest owners are currently usually made several months prior to harvesting. If the log class distributions and prices are fixed in the agreement, this time lag before logging prevents flexible timber bucking at the logging sites, and most of the economic benefits of real-time market information will never be realized.

Furthermore, competition on open wood markets will place practical constraints for setting prices according to mere production costs; if one wood procurement company is unwilling to pay for wood, some competitor may find the same logging site suitable and desirable for their needs. As long as a competitive situation remains and actors are independent, the prices cannot be declared by one actor.

5 CONCLUSIONS

With proactive use of the presented ABC models the mill managers can use the costing tools for both strategic and tactical production planning. The managers can access accurate process-based information that will help them decide which production palette is the most profitable for each market situation and how the costs are cumulated in the production. The process-oriented approach helps companies in finding production bottlenecks. One key finding was that focusing on energy-intensive aspects of production may be the most advantageous development: savings can be achieved by either improving efficiency or reducing energy acquisition costs. Careful production planning is also wise, as changes in sawing pattern will directly affect the sawing costs and the utilization rate does the same to energy production.

Although the results of our case studies are prominent because the accurate cost structures of different mills may reveal some weak spots from the cost viewpoint, the study by Drennan and Kelly (2002) clearly points out that the employees of any industry are in key roles when determining the success of a novel costing method. The motivations of workers at all levels of production must be maximized to ensure the best possible result for both the employer and employees.

The models are now enlightening the black boxes concerning price determination in the forest industry. These adaptable models can be used for estimating the most profitable wood value chains or single links of each chain. These results can be combined e.g. with pre-harvest information from airborne laser scanning to accomplish more accurate tree bucking, thus creating more value to both forest owners and the industry. Combining these upstream and downstream information flows can lead to high-yielding production mixes and thus create more added value to the business.

The models presented in papers I–IV provide several possibilities for future perspectives. There are three ways to proceed with the models. Firstly, they can be programmed using computer language more sophisticated than MS Excel spreadsheets to improve the user interface. Secondly, the models can be combined with each other to find the best possible use for the logs. Thirdly, the models can be connected to wood procurement and also to the customer end of sawmilling for optimizing the wood value chains.

According to these results, the forest industry holds great potentials, not only due to current production, but because of the potentials that can be gained via new products that can be extracted from current material flows. Several Finnish biofuel plants are closely connected with forest industry and the possibilities of using current side streams especially in chemical pulp production for gaining completely new markets are observed. As the ABC was proven to work in tested multi-product facilities, the adaptation of the method could be transferred into new and forthcoming biorefineries using the virtual greenfield concept for previewing costs and profits.

One essential challenge for future wood supply chain studies and applications is how to concurrently and separately handle all the links of the chains. Future research will be needed to find out the true applicability of the results presented in this thesis. Will the wood flows of a certain procurement area be significantly changed according to the possible production cost-based pricing of wood? In this sense, the future of wood supply chain research is secured, as there will be no lack of challenges.

The models were tested with the virtual greenfield mills and considering the remarks of the ad hoc nature of the tests, it is still noteworthy that the calculations indicate that the “old products” are competitive. In the future, raw material availability and steady product demand

are cornerstones of successful forest industry. Markets for future products are seemingly enhancing the current forest industry.

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