Internal allocations in the Swedish pulp and paper industry

Ola Svending
Stora Enso Environment
PO Box 9090
SE-650 09 Karlstad
SWEDEN

Chalmers University of Technology
Environmental Systems Analysis
SE-412 96 Göteborg
SWEDEN

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Table of content

Table of appendices

1 *Background*

This is the second report on *Allocation for site-specific handling of environmental data*. Together the reports form the basis for a licentiate thesis with the same title. The intended receivers of these reports are mainly the Swedish forest industry federation represented by SSVL[1] and its members, in particular Stora Enso. The results may also be useful for other industrial branches especially process industry.

In year 2000 a project was initiated by SSVL and coordinated by CPM[2] at Chalmers University of Technology. The scope of the project was to enhance the transparency and stringency of the pulp and paper industry's environmental data. As a result thereof repeatability and credibility of that data is expected to increase. In the project, referred to as the CPM/SSVL-project, the ISO/TS 14048 (ISO, 2002) format is implemented in the pulp and paper production sites in order to increase the transparency of the information. ISO/TS 14048 is a structure for managing documentation and communication of environmental data. To enhance the stringency of the environmental data, PHASETS[3] (Carlsson and Pålsson, 2001) was adopted to structure the models of the technical systems of the production sites.

In addition to this a manual for generation of product related environmental data has been drafted. The manual includes a framework for system boundaries, cut-off criteria, site-specific/generic information and allocations. Internal allocations were given special attention in the project, and the results are reported in this report.

Definition of internal allocation:
In this report, internal allocation is defined as the partitioning of potential environmental impacts occurring from a process (and indirectly its preceding processes) within a production site between two or more products being produced in that process.

The manual is not public, but is used internally within the pulp and paper industry for structuring environmental calculations.

About 90% of Stora Enso's pulp, paper and board production capacities worldwide (Stora Enso, 2002) have adapted to EMAS and/or ISO 14001. EMAS is the European community's voluntary Eco-Management and Auditing Scheme. When adapting to EMAS the production site commits to a continuous improvement of the environmental aspects of its operations (EMAS, 2001). An environmental report is made public presenting data and trends for environmental parameters relevant for the production site. However, different stakeholders' demand for product related environmental data is increasing. In Europe Integrated Product Policy (IPP) is setting new demands on a product focus, both in achieving improvements but also in communication of environmental data. Environmental labels and environmental product declarations set demands on how product related environmental data is generated at the production sites. The pulp and paper industry's own approach: Paper Profile is one example of this[4].

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[1] In Swedish: Stiftelsen Skogsindustriernas Vatten- och Luftvårdsforskning. Freely translated: The Swedish forest industry's environmental research foundation.

[2] CPM, Competence Center in Environmental Assessment of Product and Material Systems hosted by Chalmers University of Technology.

[3] PHASETS, PHASEs in the design of a Technical System was developed by CPM.

[4] More information on the Paper Profile is available at www.paperprofile.com.

The life cycle approach, or environmental calculations in general is used for different fields of application. Within Stora Enso the uses presented in figure 1 have been proposed.

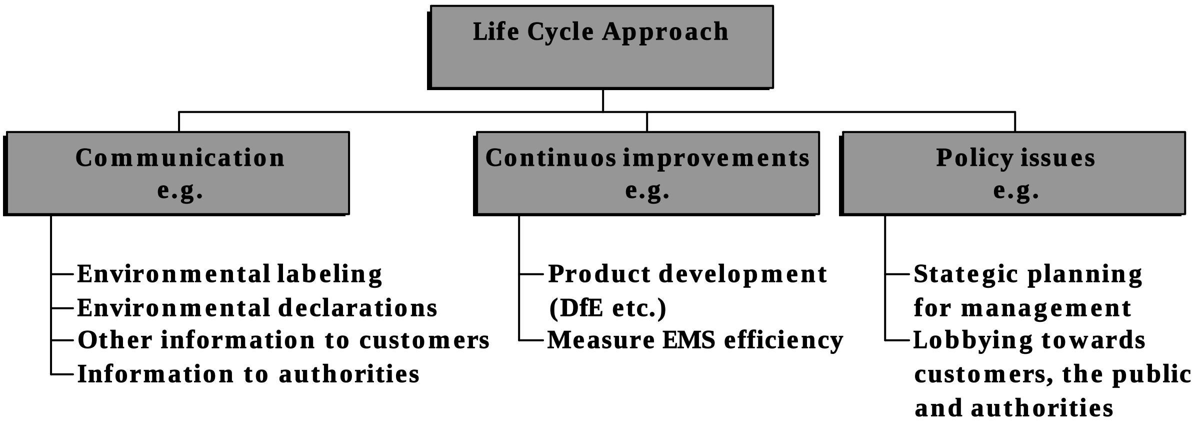


Figure 1
Proposed uses of the Life cycle approach within Stora Enso.

Allocation is not only needed for generating product related environmental data. In Finland many production sites are split between two or more organisations (divisions), each with reporting responsibility. In these cases potential environmental impacts must be allocated to the relevant divisions. Emission trading (CO_2) is another imminent issue for which allocation on products and co-products might be necessary.

2 Introduction

In the LCA community there are two schools of how to deal with multi-functionality of a production system. These views are partitioning, which is related to a retrospective view (synonyms: book-keeping, accounting, cause oriented etc.) and system enlargement, which is related to a prospective view (synonyms: change oriented, effect oriented etc.). These two approaches have been argued for frequently in the literature (e.g. Ekvall, 1999 and Weidema, 2001). Some authors claim that one approach or the other can be used for all applications, whereas others (e.g. Tillman, 2000) argue that the goal and scope of the study should determine the approach.

LCI/LCA studies carried out within the pulp and paper industry traditionally have a retrospective view aiming at presenting potential environmental aspects occurring from the production of pulp and/or paper during a specific year. Many of these studies are focusing on the cradle-to-gate perspective, using models with different levels of detail to distinguish specific products. When modelling, the practitioner first needs to identify the need of detail in the information. This sets the demands on the level of detail of the LCA model. Being aware of the escalated amount of work needed to set up and update a high dissolution model, it is desirable to use models that aggregate some sub-processes. When simplifying modelling by aggregation the need for internal allocations increase.

Though figure 1 shows that the life cycle approach also can be used to support decision-making and thereby identifying consequences of choices, in practice retrospective data is commonly used also for those applications.

Allocation procedures for open-loop recycling is not dealt with in this report (see figure 4).

The suggested procedures for internal allocations are primarily intended to be used for generation of product or product group specific environmental data. This type of data can be used for market communication (environmental declarations), internal improvement programs, environmental benchmarking of products etc. Without a common practice within the pulp and paper industry of how internal allocations shall be performed, results of separate studies cannot be compared with each other. As a result of deviating methodologies for e.g. internal allocations, decisions based on product specific environmental data may be taken on the wrong grounds.

3 *Methodology and definitions*

3.1 *Methodology*

The report is based on case studies carried out in Stora Enso production sites. The case study approach has been chosen for two reasons: (1) My position as a Stora Enso employee has allowed me the necessary insight in the production sites and (2) the consensus process succeeding this report is easier if the suggested allocation procedures can be proved feasible for the production sites. The case studies have been complemented with experiences from other businesses through literature studies. The issues studied are:

- Identifying the situations within the production sites were allocations are needed.
- Suggest possible ways of conducting appropriate allocations for those situations.
- Analyse and recommend best available practice (BAP) with experience from the case studies and what the generated environmental information is intended for.

All case studies were chosen within the Stora Enso group for accessibility reasons. The production sites were also chosen to represent different product groups and different levels of production site complexity. From the case studies general conclusions are drawn that can be applicable for other production sites within or without the pulp and paper industry.

3.1.1 Identifying internal allocation situations

The step-by-step procedure described below is used to identify an internal allocation situation.

Step 1	Describe the production site and all products (main products and by-products) produced there. If there are no co-products and the main products are similar, the product related environmental data can be obtained by a simple model and a simple allocation approach.
Step 2	A model of the technical system is drafted to help identifying the production site's internal sub-processes. Sub-processes involved only in the production of by-products are allocated to these. The model of the technical system needs to be sufficiently detailed to correspond to the desired level of detail in the environmental information.
Step 3	Identifying each sub-process's function and relevant in- and outflows. Multi input or multi output sub-processes (allocation situations) are hereby identified.

3.1.2 Addressing applicable internal allocation methods

When an internal allocation situation has been identified, the next step is to determine how the allocation problem can be solved. When communicating with different stakeholders, specific demands on e.g. how to perform site-specific allocation can be formulated by each stakeholder (Svending, 2001). These demands could force the LCA practitioner to apply different allocation methods when communicating environmental data to each stakeholder. However, most demands from the stakeholders deal with allocation on a more general level, as described in section 5.1. Finding allocation methods that correspond to the general demands presented in section 5.1 is therefore of importance. The process of determining how an allocation problem can be solved is also a step-by-step procedure:

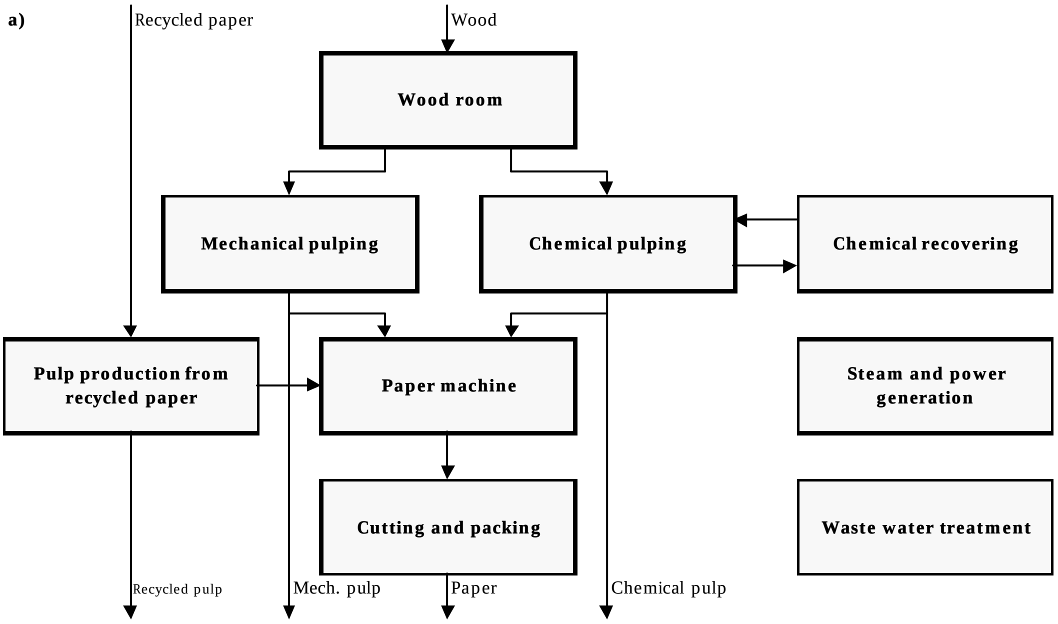
Step 4	For each identified multi input or multi output sub-processes, possible properties of the relevant flows to base an allocation upon are described. These properties can include physical properties/measured units, causal dependencies, economical values etc.
Step 5	The possibility of avoiding allocation through a further sub-division of the sub-process is investigated. A further sub-division can only be justified if the in- and outflows can be quantified, either by measurements or by assumptions. Finding the necessary level of detail without creating a too complex model is an iterative process. Keeping the model as simple as possible within the scope of the intended information is desired.
Step 6	Finally one or more methods for allocation are proposed. Each method is justified for different applications depending on the scope of the assessment. The proposed allocation methods: - Must be repeatable from one year to the other without the data on which the allocation is based changes inconsistently. - Must be based on a stringent procedure that is in line with the ISO 14041 standard (see ISO, 1998). - Must not make data public that can be sensitive for the supplier/customer relationship, e.g. production cost or supplier/supplier relationship, e.g. sheet composition.

This step-by-step procedure is referred to in the case studies of this report (section 4).

3.2 Definitions

3.2.1 Production site infrastructures

The pulp and paper production sites included in this study can schematically be described as three different cases regarding their production infrastructure; a) integrated paper production and internal production of most of the needed pulp, b) unintegrated paper production from purchased pulp only, and c) production of market pulp. See figure 2.



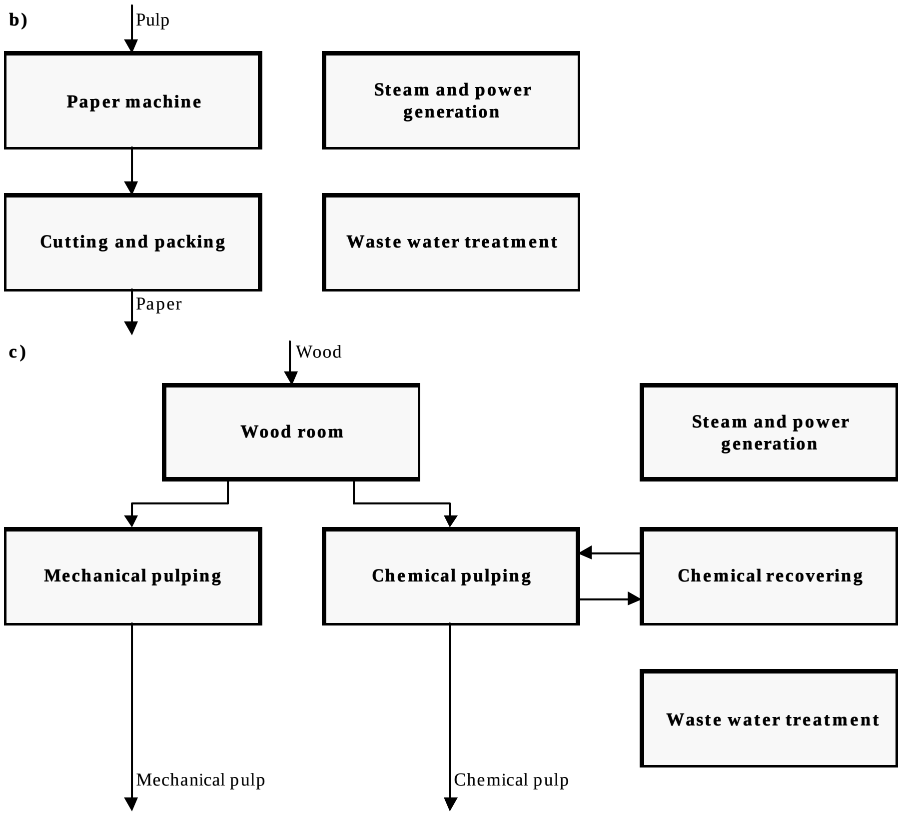


Figure 2
Production infrastructures: Case a) Integrated paper production. Note: Only a few integrated paper mills also produce market pulp. Case b) Unintegrated paper production. Case c) Production of market pulp.

3.2.2 Allocation situation

Environmental allocation is defined in the ISO standard for life cycle assessment (ISO, 1997) as “partitioning of material and energy flows to or from an activity to the product system”. An allocation situation is in this report defined as a unit process, were an allocation problem arises. Typical cases are presented schematically in figure 3. Note that this study only deals with allocations performed internally at the production site. Allocations handling e.g. recycled paper (open-loop recycling, see figure 4) are discussed for instance by Ekvall (1999).

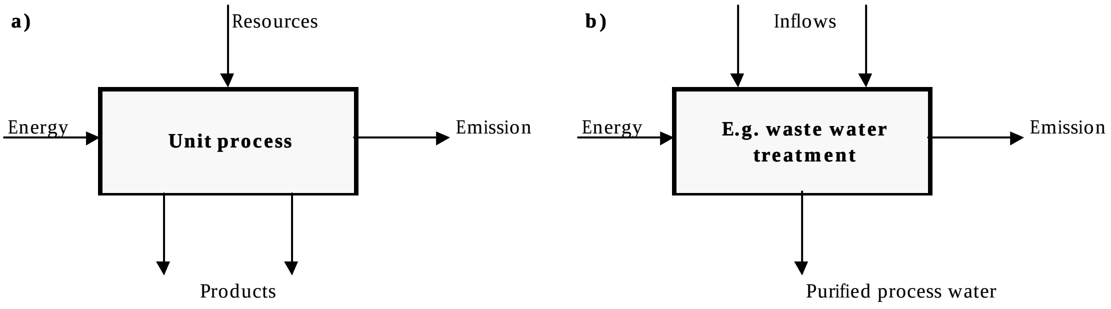


Figure 3
Two types of site-specific allocation problems; a) multi-output and b) multi-input.

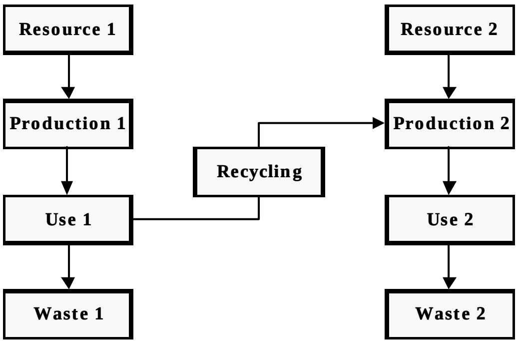


Figure 4
Open-loop recycling. This type of allocation is not dealt with in this report.

3.2.3 Basis for allocations

When performing an allocation for the types of situations described in figure 3 there is a need for a comparative basis reflecting the properties of each involved product and co-product. The comparative basis is used to provide a distribution of the potential environmental impacts of the process to each product. The ISO standard on life cycle inventory (ISO, 1998) describes a ranking list for the allocation procedure:

Procedure A:
- Avoid allocation by dividing the unit process into two or more sub-processes, or expanding the system to include the additional functions of the co-products.

If A is not possible, then procedure B:
- When allocation cannot be avoided, partitioning between the products shall reflect their underlying physical relationships, i.e. the way in- and outputs are changed by quantitative changes in the products. The resulting allocation will not necessary be in proportion to measures like the mass or molar flow of the products.

If A and B are not possible, then procedure C:
- Partitioning between the products based on other relationships, e.g. economic value of the products.

To avoid allocation by dividing unit processes into sub-processes is commonly done, but at a certain level this is no longer feasible. This level depends both on the desired detail of the generated information and also on the possibility to achieve relevant and credible information on the in- and outputs for the new sub-processes. The continuous search for finding use for co-products and close-to-waste products in a complex process industry (like a pulp and paper production site) has resulted in integrated processes that cannot easily be divided into single function sub-processes. No case study has been found where sub-division completely replaces allocation (Ekvall and Finnveden, 2001). The feasibility of dividing into sub-processes is further discussed in each case study (section 4).

Avoiding allocation by system expansion can be appropriate for studies investigating the effects of a change in e.g. a process or a supplier. The study of the environmental effects of producing e.g. one extra ton of paper is commonly facilitated by the use of marginal data. This approach has received little acceptance in the pulp and paper (and other energy intensive) industries due to the suggested use of marginal energy and the difficulty to aggregate data from different products over a life cycle.

When avoiding allocation is no longer feasible, possible underlying physical relationships are identified. The properties of the products and co-products are in many cases of different characteristics, e.g. kg pulp and MJ steam (both products from the mechanical pulping process). In these cases physical relationships are more difficult to identify and other relationships need to be established. Examples of such other relationships are the economic value (price) of the products and estimations thereof.

3.2.4 Causal relationships

The ISO standard (ISO, 1998) has a clear ranking of how allocation shall be performed. In procedure B (see section 3.2.3) allocation reflecting a change in products is presented. This implies that a causal relationship should be used. Two types of causal relationships have been proposed (Ekvall, 1999 and Tillman, 2000) as the basis for choosing allocation (partitioning) or system expansion in LCAs; cause-oriented (the relationship between the investigated system and its *causes*) and effect-oriented (the relationship between the investigated system and its *effects*). The relationship between the two causalities is illustrated in figure 5. Characteristics of the cause-oriented (also referred to as retrospective LCA) and the effect-oriented (also referred to as prospective LCA) are described in table 1. Much of the debate during the consensus process of the ISO standard (ISO 14041) was on causalities (Tillman, 2002).

Cause	→	Studied system	→	Effect
	Cause oriented causal relationship		Effect oriented causal relationship	

Figure 5
Relationship between cause oriented and effect oriented causal relationship (translated from Tillman, 1998)

Table 1
Characteristics of retrospective and prospective LCI models (Tillman, 2000).

	Type of LCA	
Characteristics	*Retrospective*	*Prospective*
System boundaries	Additivity Completeness	Parts of system affected
Allocation procedure	Reflecting causes of system Partitioning	Reflecting effects of change System enlargement
Choice of data	Average	Marginal (at least in part)
System subdivision	-	Foreground and background

Retrospective LCA is sometimes referred to as “full LCA” including all environmental aspects of raw material extraction, production, use and waste treatment. No LCA can include every detail and hence the “full LCA” is a utopia. However if a certain level of completeness is achieved, data from the production phase of one product can easily be added to another product in an assembly chain (please compare with Type III Environmental Declarations[5]). Partitioning or allocation is used to separate a specific product from a multi-product system. The allocation procedure is based on parameters reflecting the causes of the system, and Tillman (Tillman, 2000) argues that the economical value of the products can be used. The data used in the life cycle inventory (LCI) represent already passed activities, commonly expressed as an average for e.g. the last year.

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[5] One type III environmental declaration is the EPD system. More information on the EPD system is available at www.environdec.com.

Prospective LCA on the other hand is suggested to be used to identify effects of a change (Tillman, 2000), e.g. what is the environmental effect of driving additionally 1 km with a certain vehicle. When doing these assessments only the parts of the system affected by the choice need to be included in the study. Instead of allocation, the system is expanded to identify the potential environmental effects of a specific product of a multi-product system. The expanded system reflexes the avoided production of co-products of the multi-product system. Instead of using average data in the inventory, efforts must be made to find the relevant marginal data. I.e. if we increase the steam consumption, how is that extra steam generated. Sometimes it is convenient to divide the prospective LCI model into a foreground system (in which the activities can be controlled, e.g. a pulp mill operations) and a background system (in which the activities are more difficult to control, e.g. the electricity mix delivered to that mill).

4 Case studies

In this section three case studies from Stora Enso production sites are presented. These have been selected to get a broad view of different kinds of production sites that set different demands on how allocation needs to be dealt with. The methodology presented in sections 3.1-3.2 is taken into account to describe and to suggest applicable allocation methods that correspond to the needs of the production site's stakeholders. In the case studies, references are made to the steps (1-6) of the methodology.

4.1 Skoghall Mill

4.1.1 Production site and products

In this section the production site and all its products are presented (step 1 of the methodology). The Skoghall Mill is an integrated board mill located 10 km south of Karlstad, Sweden. The site includes two board machines, production of kraft pulp (unbleached and bleached sulphate pulp), mechanical pulp (CTMP), energy production, pollution reduction facilities etc. (Skoghall Mill, 2001). A schematic process flowchart of the Skoghall Mill is presented in appendices A-D, where appendix A gives an overview.

The products include Liquid Packaging Board, Coated Kraft Back and White Top Liner, used for packaging of food products. These products are illustrated in figure 6.

Figure 6
Examples of products where board from the Skoghall Mill is used.

Below a number of important departments of the Skoghall Mill are presented.

Wood room

Wood from spruce and pine (roundwood and sawmill chips) is delivered to the wood room. The roundwood is debarked and then chipped. In these operations electricity, steam and some sodium hydroxide (NaOH) is consumed and wastewater and bark generated. In parallel, chips from external sawmills are screened and stored. During these operations only electricity is consumed. The wood room is schematically illustrated in figure 7.

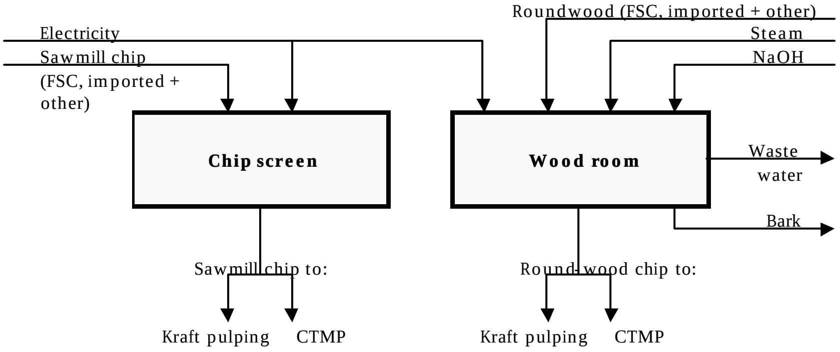

Figure 7
Process illustration of the wood room at the Skoghall Mill.

The electricity consumed for screening and storing sawmill chips is not easily separated from the consumption in the remaining wood room.
The main products sawmill chips and roundwood chips are measured separately in m^3sub/time period. Internally these flows have designated economical values, SEK/m^3sub. The by-product bark is used as fuel in the internal bark boiler. The weight or volume of the bark is thus irrelevant to measure due to variations in its moisture content. Instead the flow of steam is measured (in MJ) after the combustion of the bark. This flow can also be given an economical value SEK/MJ generated steam.

Digester, washing filters and oxygen delignification

Woodchips from the wood room are fed into the top of the digester together with white liquor. At the bottom of the digester the white liquor has turned into black liquor, which is removed from the pulp. The recycling of the liquor is further described below (Chemical recycling). The pulp is then cleaned in the washing filters and pre-bleached in the oxygen delignification. This is also illustrated in appendix B along with the kraft pulp bleaching (also further described below).
The outflows of kraft pulp and black liquor from the digester is difficult to allocate between, since the properties of the two flows are rather dissimilar. The pulp is the main product of the two and is measured in kg per time period. The flow of liquor is not measured as such, but as effective alkali and sulphidity. Both properties are important factors for the process monitoring in the digester.

Chemical recycling unit

The chemical recycling unit has two main functions. Firstly, the chemicals (liquor) used for digesting woodchips are recycled (chemical recycling) and secondly, steam is generated from the combustion of black liquor (energy production) according to appendix C. As described above, the flow of liquor is not relevant to measure. The steam is measured in MJ per time period.

Turpentine and crude tall oil production

In these two separate processes, raw-turpentine and black liquor soap are extracted in the chemical recycling unit and then refined to the co-products turpentine and crude tall oil. Both co-products are measured in kg and have prices determined by the market. Both co-products are then sold to external customers.

Kraft pulp bleaching

Some of the kraft pulp production is bleached using an elementary chlorine free (ECF) process. No allocation problems arise in this process step. However all emissions of chlorine compounds (e.g. ClO_2 and chlorate) are assumed to origin in this process step.

CTMP production

Part of the woodchips (mainly sawmill chip) is used to produce CTMP. In the process of refining the wood excess steam is generated which is used in other parts of the mill. The CTMP is measured in kg per time period and the steam in MJ per time period. An allocation between these two flows needs to be done. Appendix D presents an illustration of the CTMP production.

Board machines

The two board machines (BMs) at the Skoghall Mill are referred to as BM 7 and BM 8. Unbleached kraft pulp, bleached kraft pulp, CTMP, externally purchased short fibre pulp, internally circulated broke and additives are feed into the board machines. The machines are powered by electricity and steam of different pressures. Due to lack of relevant data on energy consumption on each machine, it is not possible to distinguish one from the other. Therefore these are regarded as one in the model for product related environmental information. The product specification used to adjust the board machine and the inputs of pulps and chemicals to produce different products, is also used to distinguish different products in the product related environmental calculations. This approach makes allocation for this sub-process unnecessary, since only one product at a time is considered. An example of a product specification is presented in appendix E (in Swedish only).

Energy production

Steam is produced in several locations; two recovery boilers, bark boiler, oil boiler, CTMP production, sulphur burner and odorous gas kiln. The steam is also produced with different (higher) pressures, and some of it is used internally to generate electricity. After the electricity generation steam is delivered to the other sub-processes at two (lower) pressures.

Wastewater treatment plant

Wastewater flows from different parts of the Skoghall Mill are feed into different points of the wastewater treatment plant. The purification of the wastewater is done mechanically (two sedimentation basins), chemically (two precipitation basins) and biologically (one aerated lagoon). Sludge is separated and thickened in two locations. The purified water is then led into lake Vänern. The wastewater flows and COD concentrations are measured at several points in the wastewater treatment plant, making it possible to map out the internal origin of the water pollution. Parameters as P-tot, N-tot and AOX are only measured as they reach the receiving water. In this unit process the problem is how to allocate the consumption of energy and additives using a relevant basis.

Chemical preparation

The chemical preparation is a sub-process in which several chemicals are produced: Chlorine dioxide (ClO_2), sodium sulphate ($NaSO_4$), sodium sulphite (Na_2SO_3) and sulphur dioxide (SO_2). These chemical products are then used at different locations within the Skoghall Mill, but also sold to external users located onsite. In the production of SO_2, $NaSO_4$ and Na_2SO_3, sulphur is burned which also generates steam. See figure 8. This is a typical multi-output process for which further division into sub-processes is limited due to insufficient measuring systems.

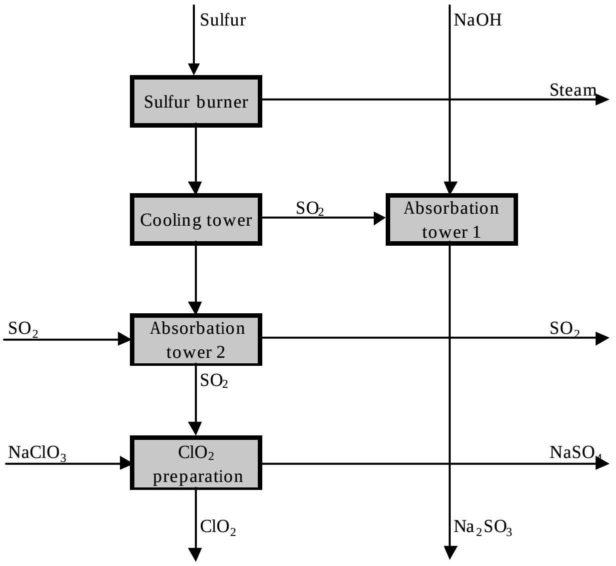

Figure 8
Process illustration of the chemical preparation at the Skoghall Mill.

Solid waste

Several fractions of solid waste are collected at the Skoghall Mill. The nature of some of these fractions makes it easy to trace them back to their origin (e.g. green liquor sludge origins at the chemical recycling unit). Other fractions need to be allocated. Each fraction's wet-weight is measured as it is transported to landfill etc.

Other activities

At the Skoghall Mill other activities than those listed above also take place, e.g. packaging of products, service and maintenance of production equipment, development of products and processes and marketing. If any of these activities shall be included in the assessment of a product, they may be collectively dealt with in "Other activities".

Adjacent companies

The Skoghall Mill has three relevant adjacent companies affecting the production site's environmental situation. These are presented in table 2.

Table 2
Relevant adjacent companies to the Skoghall Mill.

Company	*Operations*	*Relation to the Skoghall Mill*
Tetra Pak	Laminates paperboard with PE before it can be printed.	Tetra Pak is a customer of the Skoghall Mill. Tetra Pak purchases liguid packaging board, but also some services like waste management.
Noviant	Production of e.g. Carboxyl Methyl Cellulose (CMC) for the food industry.	Noviant purchases electricity, steam and some chemical products from the Skoghall Mill and also uses the Skoghall Mill's wastewater treatment plant.
Akzo Nobel	Produces NaOH and other chemical products.	Akzo Nobel uses the Skoghall Mill's wastewater treatment plant and landfills. NaOH is delivered to e.g. the Skoghall Mill through a pipeline.

4.1.2 Model of the technical system

In this section a model of the technical system is presented (step 2 of the methodology). The model for calculations of product related environmental information at the Skoghall Mill was developed to periodically supply customers and the internal development department with environmental information on present and future products. Also small variations in pulp composition and/or board stiffness must be possible to reflect in these calculations. The model is also used to map the different production departments' contributions to the production site's environmental aspects according to ISO 14001 (ISO, 1996). The structure of the current model is presented in figure 9. The modelled processes may incorporate several departments of the Skoghall Mill. These processes are described in the following section.

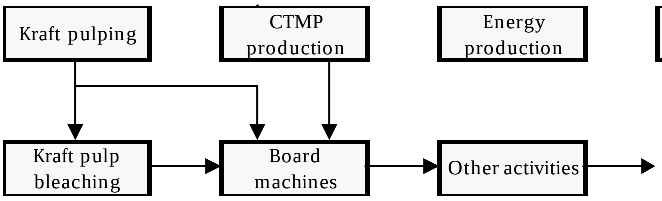

Figure 9
Structure of model for product related environmental data at the Skoghall Mill.

4.1.3 The sub-process's function and relevant flows

In this section steps 3-6 of the methodology are dealt with. Firstly each identified sub-process's function and relevant in- and outflows are presented. Secondly the possible properties of the different flows which an allocation may be based upon are described and the possibility to avoid allocation through further sub-division is discussed. A suggested allocation method is recommended for each relevant sub-process. These steps are repeated for each identified sub-process. In section 5 these suggested allocation methods are analysed further.

Kraft pulping

The model for kraft pulping is an aggregation of the sub-models; wood room, digester and part of the chemical recycling unit, as illustrated in figure 10. Each of these is further looked into (table 3) to sort out the site-specific allocations performed there.

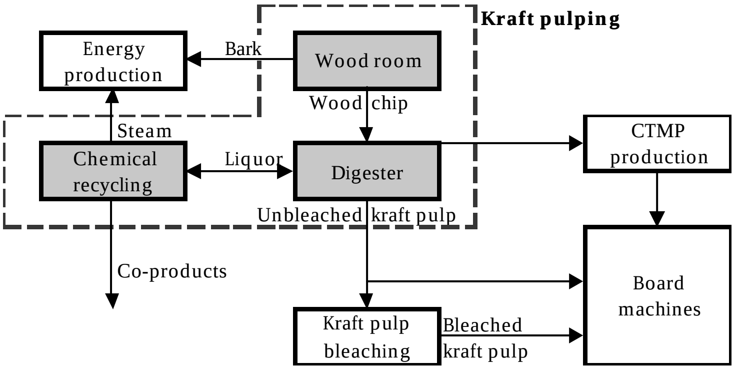

Figure 10
Skoghall Mill: The model for kraft pulping and its surrounding models.

The chemical recycling unit has two main functions, which in the model are split upon two separate unit processes. In reality these two unit processes are only one sub-process: Chemical recycling. Firstly, the chemicals (liquor) used for digesting woodchips are recycled and secondly (chemical recycling), steam is generated from the combustion of black liquor (energy production). Co-products are also extracted from the chemical recycling process. The energy production is further dealt with in a later section.

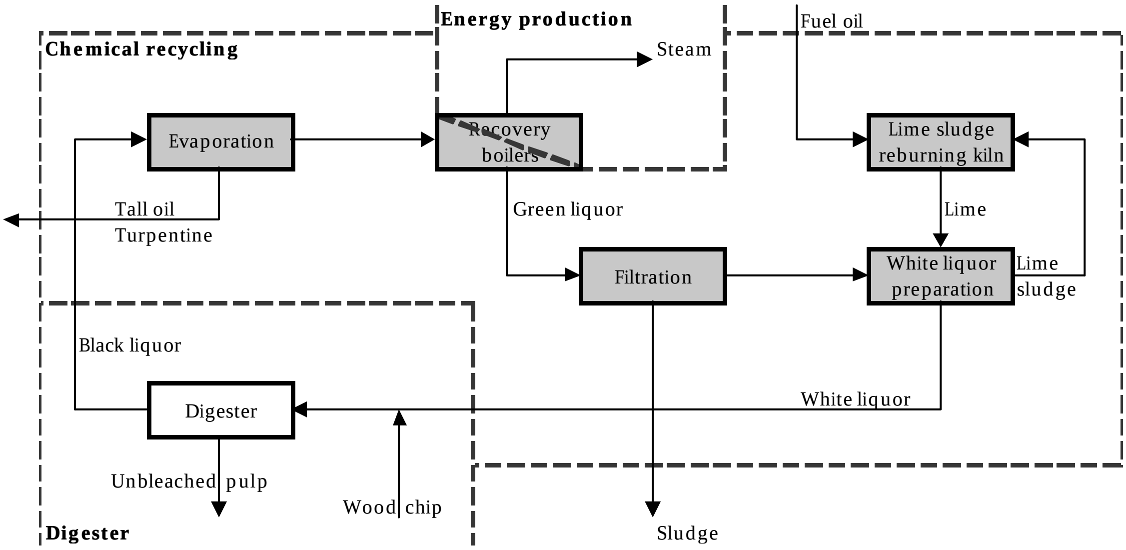

Figure 11
Skoghall Mill: Magnification of the model for the chemical recycling and part of the energy production.

Table 3
Kraft pulping at the Skoghall Mill: Description of relevant flows regarding allocation methods.

	Description
Wood room	Roundwood is debarked and chipped. Roundwood and sawmill chips are stored in stacks before transported to the digester and the CTMP. Only small amounts of the wood room's total electricity and internal transportations are used for handling the sawmill chips, as they are delivered in the desired state. The major amounts of the wood room's total electricity and internal transportations are used for debarking and chipping of the roundwood chips. Bark is transported to the solid fuel burner (P12).
- Bark	The main part of the bark is used internally as a fuel. Its energy content varies due to e.g. the varying dry content. This flow is therefore not measured directly, but as the energy generated after combustion of the bark (MJ). A minor part of the bark is also sold to external customers. The bark has therefore also a market related price (SEK/kg). Formerly bark was landfilled as waste.
- Wood chips to CTPM production	The wood chips are measured in m^3sub. The main part of the sawmill chips delivered to the Skoghall Mill is used at the CTMP production. The wood chip has an internally determined price (SEK/kg).
- Wood chips to digester	The wood chips are measured in m^3sub. Wood chip to the digester is the internal flow within the kraft pulping that connects the wood room and the digester. The wood chip has an internally determined price (SEK/kg).
Digester and Chemical recycling	Wood chips are boiled in a continuous digester using boiling liquor. The boiling liquor is recycled in a double loop, one recycling the boiling liquor and one reburning lime. The chemical recycling unit also generates steam. In the model, the recycling of liquor (boiling chemicals) and the digester are included in the same unit process (see figure 11).
- Unbleached kraft pulp	The unbleached kraft pulp is the main product of the kraft pulping unit process. The pulp is measured in kg, and an internal price (SEK/kg) is also available.
- Steam	High pressure steam (4 MPa) is measured in MJ and has also an internally determined price (SEK/MJ).
- Co-products	Tall oil and turpentine are co-products sold to external customers at a price determined by the market. The tall oil can be used both for its energy and material properties. The co-products are measured in kg and have market related prices (SEK/kg).
- Black and white liquors	The black and white liquors are intermediate products within the unit process and do not cause an allocation problem.

Suggested allocation method

Wood room: For simplification reasons and due to the relatively harmless environmental aspects of handling bark and sawmill chips in the wood room, all potential environmental aspects are allocated to the wood chips that are delivered to the digester and thus to the kraft pulping sub-process.

Digester and chemical recycling: The chemical recycling unit is functionally split, so that the emissions to air, ashes and other solid waste and the use of supplementary fuels associated with the combustion of black liquor within the chemical recycling unit are allocated to the steam generated there. The steam is then delivered to the energy production.

Co-products: Normally no allocation is done for the co-products. If demanded allocation on the co-products can be based on the market value of the products (SEK/year).

Alternative allocation method

Instead of splitting up the recovery boiler into the two suggested functions (energy production and chemical recycling), it could be possible to create a model that includes a sub-process called “recovery boiler”. Since the flow of liquor between the recovery boiler and the digester is not measured, this approach has been abandoned. It can also be possible to create a model that includes the entire recovery boiler in the digester sub-process. This approach results in a lower resolution model and other allocation problems as another multi-product activity is generated.

Kraft pulp bleaching

About half of the unbleached kraft pulp is bleached in the kraft pulp bleaching process. In addition to the bleaching operations, the preparation of chemicals is included in the sub-process. In the chemical preparation, chlorine dioxide is prepared along with other chemical products (sulphur dioxide, sodium sulphate and sodium sulphite) and steam. The sub-process is presented in figure 12 and the relevant flows are presented in table 4.

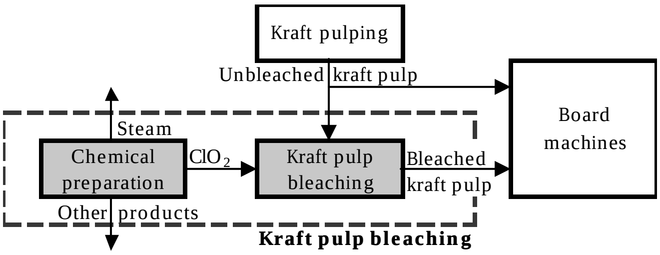

Figure 12
Skoghall Mill: The model for kraft pulp bleaching and its surrounding models.

Table 4
Kraft pulp bleaching at the Skoghall Mill: Description of relevant flows regarding allocation methods.

	Description
Steam	The steam produced in the chemical preparation plant is transferred to the mill’s low-pressure stem net via the energy production unit. The steam is measured in MJ. The steam has also an internal price (SEK/MJ).
Other products (SO_2, $NaSO_4$ and Na_2SO_3)	The other chemical products are consumed within the Skoghall Mill or sold to the adjacent companies. They are measured in kg and have an internally determined price for internal consumption and/or a contract price for adjacent companies (SEK/kg).
ClO_2	In this unit process the flow of ClO_2 is an internal flow, for which allocation is unnecessary. This flow connects the environmental aspects of the chemical preparation with the kraft pulp bleaching. This simplification is possible only if ClO2 is considered the main product of the chemical preparation.
Bleached kraft pulp	Bleached kraft pulp is considered the main product of the sub-process (kg).

Suggested allocation method

Normally all environmental aspects of this sub-process are allocated to the main product (bleached kraft pulp).

Alternative allocation method

If required by the adjacent companies, allocation on the other chemical products (SO_2, $NaSO_4$ and Na_2SO_3) can be related to the market value of products.

CTMP production

Chemi-thermomechanical pulp is produced from wood chips delivered by the wood room (part of the kraft pulping). The CTMP production delivers two products: CTMP and steam. See figure 13. The steam is generated by frictional heat in the refiners in the CTMP production. The flows are described in table 5.

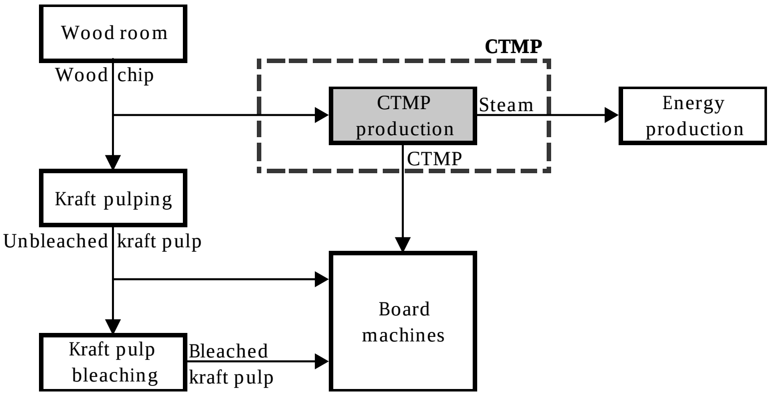

Figure 13
Skoghall Mill: The model for the CTMP production and its surrounding models.

Table 5
CTMP production at the Skoghall Mill: Description of flows regarding allocation methods.

	Description
CTMP	The CTMP is considered the main product of the unit process. The pulp is measured in kg and it has an internal price (SEK/kg).
Steam	The steam is a co-product that is measured in MJ. It is transferred to the high pressure internal steam net. The steam has a price (SEK/kg) determined internally.

Suggested allocation method

All environmental aspects of this sub-process are allocated to the main product (CTMP).

Alternative allocation method

Alternatively the internally determined price of the CTMP and steam can be used as a basis for allocation. However there are uncertainties in the internal price, as described in section 5.2.2

Board machines

The board machines are supplied with pulps from the kraft pulping, kraft pulp bleaching and the CTMP production. Additionally, short fibre pulp is purchased from external suppliers and internally recycled broke is used. See figure 14. The broke is recycled internally in the board production, and thus does not give rise to an allocation situation. Therefore all environmental aspects occurring at the board machines are allocated to the studied product.

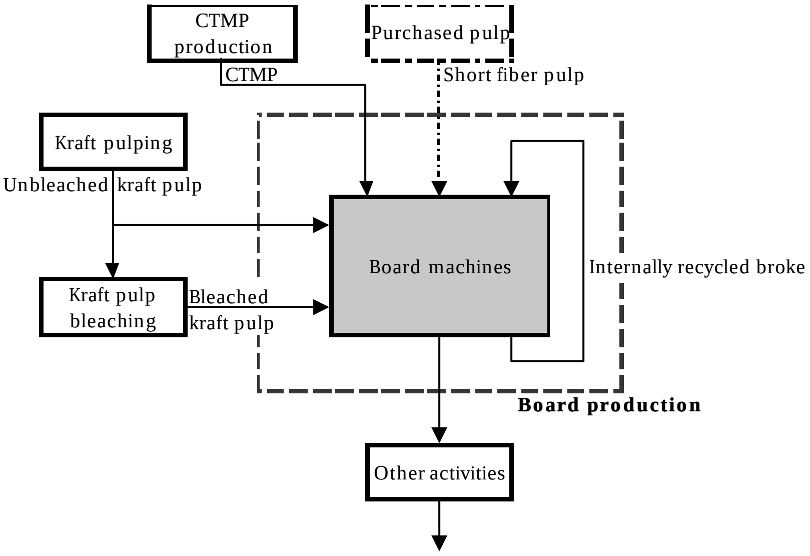

Figure 14
Skoghall Mill: The model for board production and its surrounding models.

Energy production

The energy production in the Skoghall Mill's model is schematically divided into three parts; steam production for kraft pulping (recovery boilers, P12 internal bio-fuels, CTMP, odorous gas kiln, sulphur burner), steam production for the remaining mill (P12 external bio-fuels and P11, fossil fuel) and internal electricity production (turbines 8 and 9). In the energy production, both internally produced and externally purchased fuels are used. Additional electricity is purchased from the Swedish grid. Some steam and electricity is delivered to other industries within the industrial park. Hot water is also delivered to the municipal district heating system. Figure 15 and 16 and table 6 presents the relevant flows of the energy production.

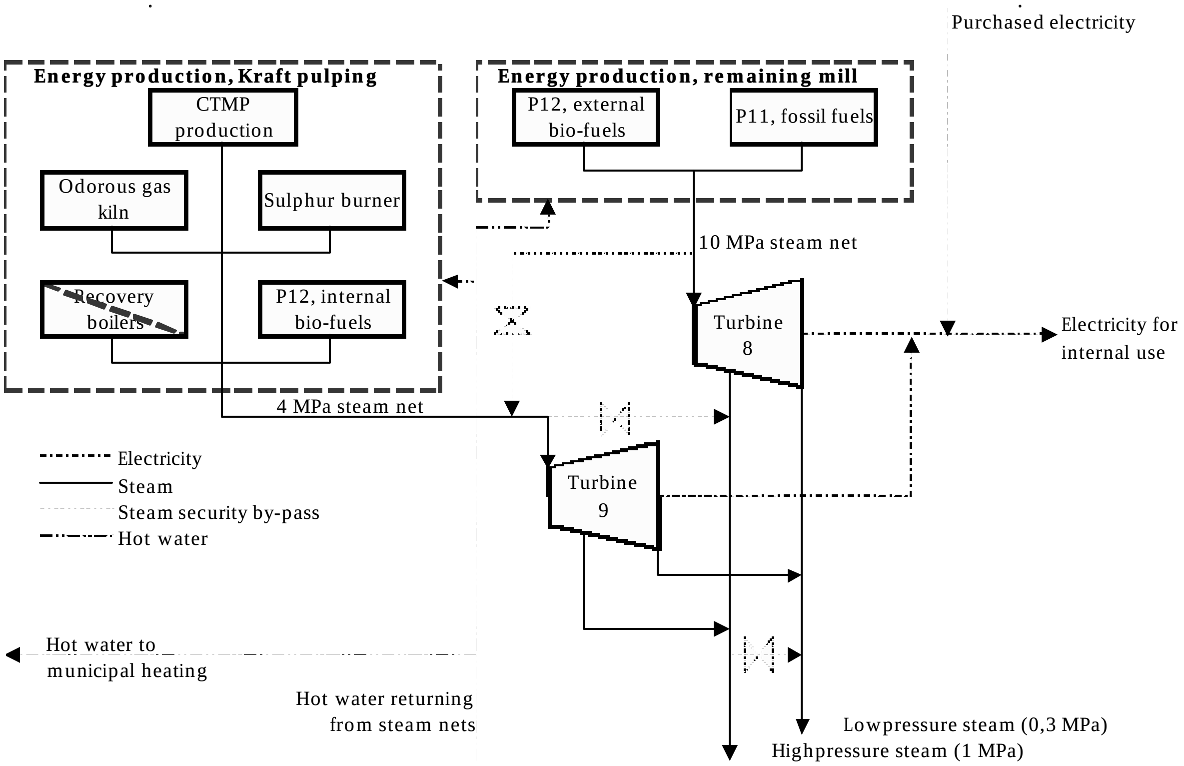

Figure 15
Skoghall Mill: The model for energy production.

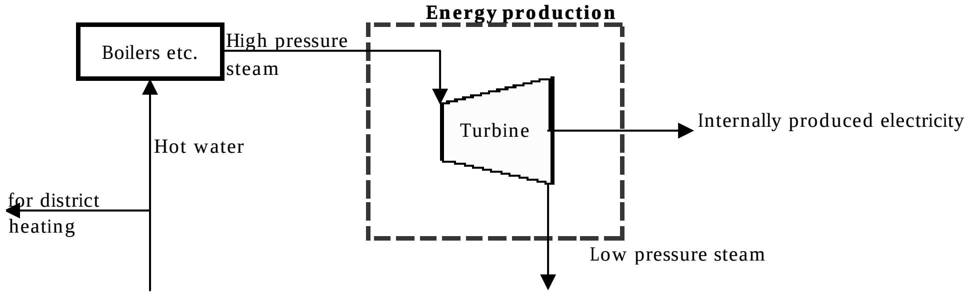

Figure 16
Skoghall Mill: Definition of the energy production flows for the allocation method.

Table 6
Energy production at the Skoghall Mill: Description of flows regarding allocation methods.

	Description
Internally produced electricity	Energy from the high pressure steam is taken to generate electricity. The internally produced electricity is measured in kWh and its price equals the price of the purchased electricity (SEK/kWh).
Low pressure steam	The reduced high pressure steam is consumed at the mill as low pressure steams, measured in MJ. Steam has an internally determined price (SEK/MJ).
Hot water for district heating	After steam and hot water has been used internally, surplus heat is sold to the municipal district heating net. The flow of hot water for district heating is measured in MJ and it has a contracted price (SEK/MJ).

Suggested allocation method

Three different allocation bases are evaluated in appendix F. From those the allocation based on turbine efficiency is recommended. When using the turbine efficiency, account is taken to the energy content of the steams and the internally produced electricity, but also to the turbine's efficiency. The loss in the turbine is subtracted from the energy generated as electricity, which results in a higher allocation factor for the internally produced electricity since the electricity has a higher quality than the steam.

The hot water for district heating is facilitated by surplus heat, which is a close-to-waste product. The contracted price for the hot water covers only the installation costs to the municipal district heating net. No real profit is made on the delivery. Therefore, no allocation is performed for the hot water for district heating.

Alternative allocation method

In cases where the internally produced electricity is in focus, the exergy approach should be preferred as a basis for allocation. Allocation based on energy content only should be motivated thoroughly.

Wastewater treatment plant

The Skoghall Mill's wastewater treatment plant is schematically illustrated in figure 17. Wastewater from different process steps is lead to the WWT plant in different wastewater flows. The wastewater flows are then purified in different steps. Wastewater from external industries (Noviant and Akzo Nobel) is also purified. The purification is facilitated physically (sedimentation), chemically (precipitation) and biologically (aerated lagoon). The separated sludge is thickened and treated as waste/by-product.

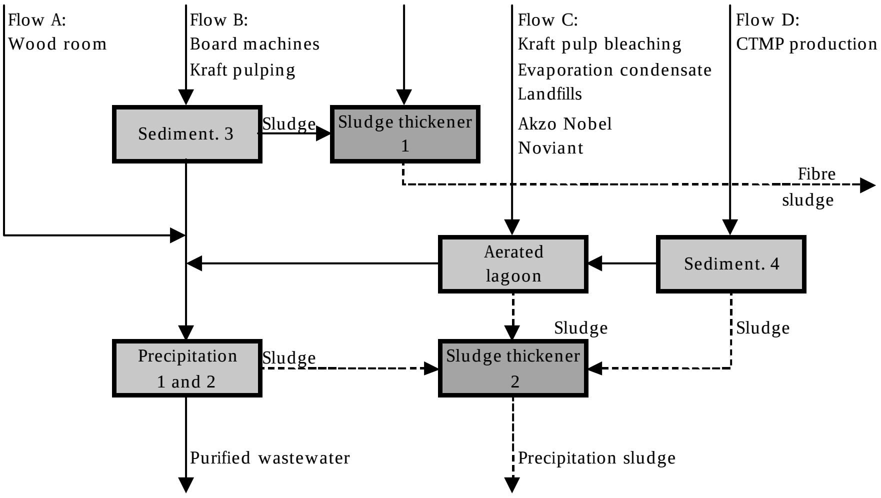

Figure 17
Skoghall Mill: The model for the wastewater treatment (WWT) plant.

The purification efficiencies (η) for the different purification steps are measured regularly to meet demands from the local authorities. These can be expressed as in table 7.

Table 7
Skoghall Mill: Expressions for purification efficiencies (h) for the different purification steps (0<h<100%).

	Chemical oxygen demand, COD (kg/m^3)	*Suspended solids, SS (kg/m^3)*
Sedimentation 3	η(COD, S3)	η(SS, S3)
Sedimentation 4	η(COD, S4)	η(SS, S4)
Aerated lagoon	η(COD, AL)	η(SS, AL)
Precipitation 1 and 2	η(COD, P12)	η(SS, P12)

From table 7 the total purification efficiency for the different wastewater flows (A-D in figure 17) can be calculated. These are presented in table 8.

Table 8
Skoghall Mill: Calculation of the total purification efficiency for the different wastewater flows.

	Purification efficiency, COD	*Purification efficiency, SS*
Flow A: Wood room	η(COD, P12)	η(SS, P12)
Flow B: Kraft pulping, Board machines	η(COD, S3) + [1 - η(COD, S3)] * η(COD, P12)	η(SS, S3) + [1 - η(SS, S3)] * η(SS, P12)
Flow C: Kraft pulp bleaching, Condense, Landfills, Akzo Nobel, Noviant	η(COD, AL) + [1 - η(COD, AL)] * η(COD, P12)	η(SS, AL) + [1 - η(SS, AL)] * η(SS, P12)
Flow D: Mechanical pulping (CTMP)	[η(COD, S4) + [1 - η(COD, S4)] * η(COD, AL)] + [1 – [η(COD, S4) + [1 - η(COD, S4)] * η(COD, AL)]] * η(COD, P12)	[η(SS, S4) + [1 - η(SS, S4)] * η(SS, AL)) + [1 – [η(SS, S4) + [1 - η(SS, S4)] * η(SS, AL)]] * η(SS, P12)

Table 9 describes the relevant flows in the wastewater treatment plant.

Table 9
Wastewater treatment plant at the Skoghall Mill: Description of flows regarding allocation methods.

	Description
Flow A-D	Allocation is based on the COD and SS algorithms presented in table 8.
Fibre sludge	The fibre sludge is reused as fibre material in external paper production. The fibre sludge is measured in kg and has a market related price (SEK/kg).
Precipitation sludge	The precipitation sludge is used as mould and/or combusted internally in the bark boiler. The fibre sludge is measured in kg and has a market related price (SEK/kg).

Suggested allocation method

This model deals with both multi input and multi output allocation situations. The multi input allocation is based on the algorithms on COD and SS emissions on the different wastewater flows presented in table 8. The consumption of electricity and purification chemicals can be allocated on the wastewater flows based on their COD- or SS-content. COD is preferred to base the allocation upon, since SS is no longer reported to the authorities. All AOX and chlorate is assumed to origin from the kraft pulp bleaching, where ClO_2 is used as one of the bleaching agents. The origin of the nutrients (P and N) is unclear. They can therefore not be allocated on a specific sub-process, but are distributed equally on all board products. No allocation is performed on the co-products (different types of sludge).

Other activities

The other activities include wrapping of products, maintenance, service, administration and any other activity that cannot be related to a specific sub-process. Any in- or outflows related to these activities are allocated on the different products equally (per ton of product).

4.2 Hylte Mill

4.2.1 Production site and products

In this section the production site and all its products are presented (step 1 of the methodology). Hylte Mill is located in Hyltebruk some 50 km north east of Halmstad in Sweden. The site includes production of Newsprint on four paper machines, production of thermo mechanical pulp (TMP), groundwood pulp and waste paper pulp, and production of energy (steam and electricity) in four boilers (Hylte Mill, 2000). Some additional pulps are purchased from external suppliers.

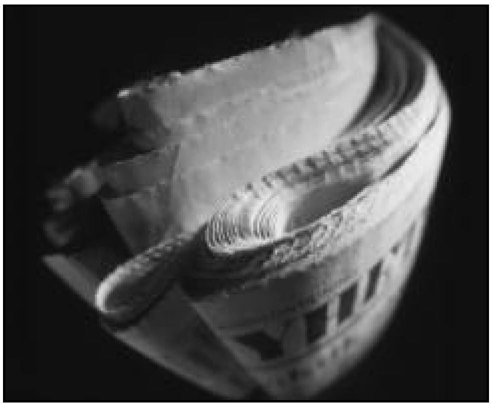

Figure 18
Example of product where paper from the Hylte Mill is used.

Below the important departments of the Hylte Mill are presented.

Wood room

Roundwood logs from softwood are processed to woodchips.

TMP production

Woodchips from the wood room are processed to thermomechanical pulp. Electricity is consumed in this process and hot water and steam are co-products.

Groundwood pulp production

Roundwood logs taken directly from the suppliers without any processing in the wood room are ground to pulp. Electricity is consumed also in this process and hot water and steam are co-products.

De-inking process

Deinked pulp is produced from recovered daily and weekly newspapers in a mechanical process. The ink is skimmed off using an addition of soap. The rest-ink is incinerated internally.

Paper production

The newsprint paper is produced on four paper machines.

Energy production

The mill can use its four different boilers to produce energy, each designated for a different type of fuel (biogas, recovered wood and paper, pressed wastewater sludge, ink from recovered paper, wood fuel, peat, natural gas, coal and oil).

Wastewater treatment

The wastewater treatment plant includes sedimentation, active sludge treatment and chemical precipitation in two parallel lines reconnected after each step. See figure 19.

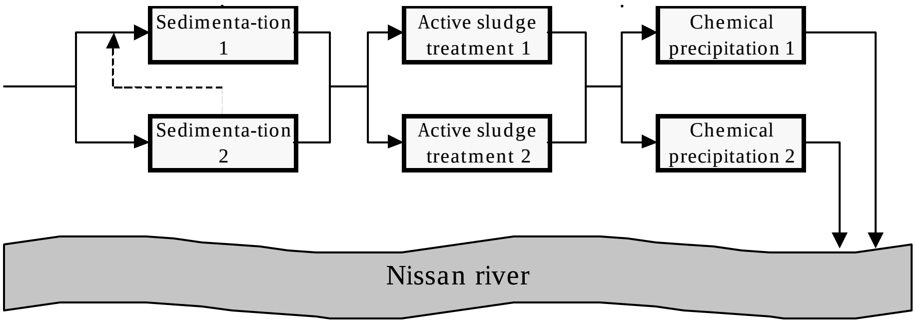

Figure 19
Process illustration of the wastewater treatment plant at the Hylte Mill.

4.2.2 Model of the technical system

In this section a model of the technical system is presented (step 2 of the methodology). First a simple model containing only a single unit process is presented. Then an alternative model containing sub-models is presented.

Single unit process

The existing model for generation of product related environmental information includes only one unit process representing the entire production site. It was developed to enable communication of product specific environmental information, e.g. Paper Profile. In this case the allocation is based on each products grammage related to the average grammage. This approach is feasible due to the similarity between the products of the production site (small variations in sheet composition and similar end uses) and the low level of detail in the information required by the stakeholders. The single unit process is schematically illustrated in figure 20. The relevant flows are described in table 10.

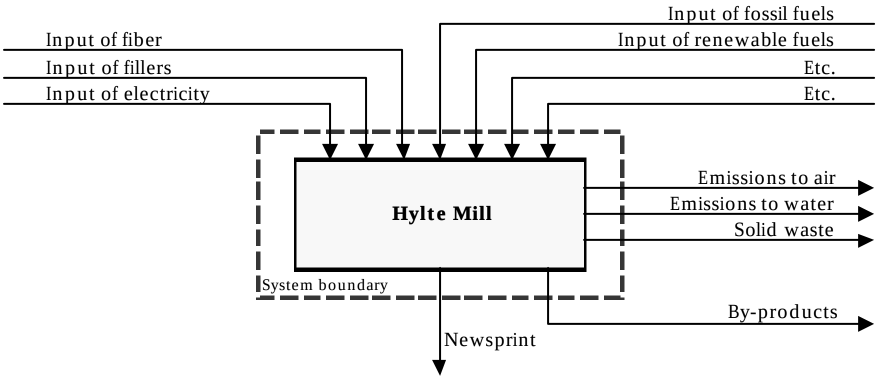

Figure 20
The single unit process model for product related environmental data at the Hylte Mill.

Table 10
Single unit process at the Hylte Mill: Description of relevant flows regarding allocation methods in the alternative model.

	Description
Newsprint (45 g/m^2, 48 g/m^2, 52 g/m^2 and 54 g/m^2)	The different Newsprint products are similar in pulp and filler composition. Each product has a specific grammage (g/m^2) and the production is measured in tons. All newsprint products have similar sheet composition (in %).
Hot water to district heating	Hot water is delivered to the municipal district heating system. The flow of hot water is measured in MJ. A contracted price (SEK/MJ) is also set for the hot water.

<u>Suggested allocation method</u>

Allocation on the different newsprint products is based on each products grammage related to a theoretical average product. No allocation is performed on the co-product (hot water), due to its small economical relevance.

<u>Alternatively allocation method</u>

If specifically requested allocation on co-products can be performed based on the products’ economical value.

Alternative model

The single unit process described above needs to be broken down for applications where a more detailed mapping of the environmental loads is needed. Examples of such future applications are benchmarking of integrated pulp production or identification of a departments contribution to the mill’s environmental aspects. An alternative model containing more details is suggested in figure 21.

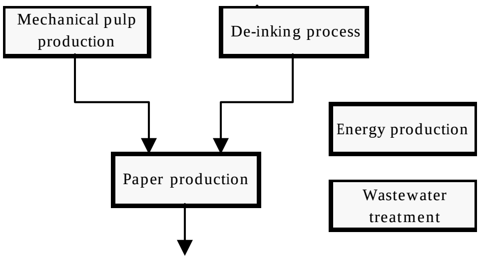

Figure 21
The alternative model for product related environmental data at the Hylte Mill.

4.2.3 The sub-process's function and relevant flows

In this section steps 3-6 of the methodology are dealt with. Firstly each identified sub-process's function and relevant in- and outflows are presented. Secondly the relevant flows and properties on which an allocation may be based are described and the possibility to avoid allocation through further sub-division is discussed. A suggested allocation method is recommended for each relevant sub-process. These steps are repeated for each identified sub-process. In section 5 these suggested allocation methods are analysed further.

Mechanical pulp production

A model for mechanical pulp production including wood room, TMP production and groundwood production is illustrated in figure 22. Wood is delivered to the wood room, where wood chips are produced. Bark from roundwood is removed and used for energy generation. Mechanical pulp is produced in two separate processes (TMP production and groundwood production). Steam is also generated in those processes.

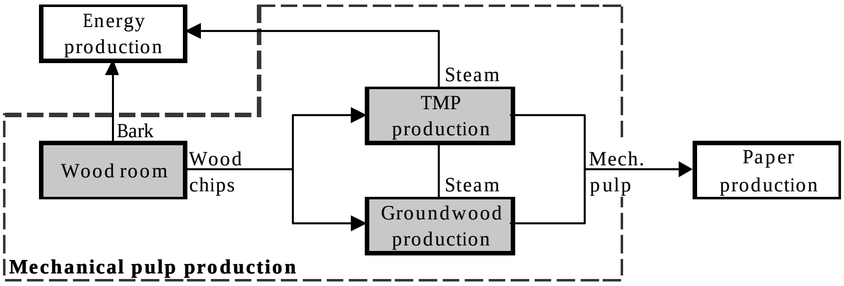

Figure 22
Hylte Mill: The alternative model for mechanical pulp production and its surrounding models.

The mechanical pulp production is a multi output process for which allocation problems occur for the three products; mechanical pulp, steam and bark, as described in table 11.

Table 11
Mechanical pulp production at the Hylte Mill: Description of relevant flows regarding allocation methods in the alternative model.

	Description
Mechanical pulp	The mechanical pulp (including both TMP and groundwood pulp) is measured in kg and has an internal price (SEK/kg).
Bark	The bark from the wood room is incinerated at the production site. The heat from the incineration is used to generate steam, which is measured in MJ. The steam has an internal price (SEK/MJ).
Steam	In the grinding of the fibers (TMP and groundwood production), excess steam is released from the process. The steam is transferred to the energy production sub-process and then used on various locations at the mill. The steam is measured in MJ. The steam has an internal price (SEK/MJ).

Suggested allocation method

The allocation between the three products is based on the internal price of the products. These prices can be estimated so that 100% is allocated on the main product (mechanical pulp).

De-inking process

The model for the de-inking process is presented below. Only one product is produced here and no internal allocation problems arise for this sub-model. De-inking sludge from the process is considered to be a waste combusted internally.

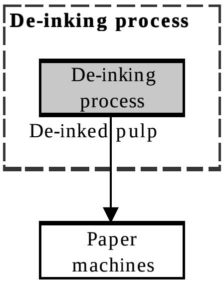

Figure 23
Hylte Mill: The alternative model for paper production.

Paper production

Paper is produced on four paper machines. It is here suggested that these are not considered individually. This approach is a simplification for the practitioner and a way to avoid assumptions needed to distinguish each separate machine.

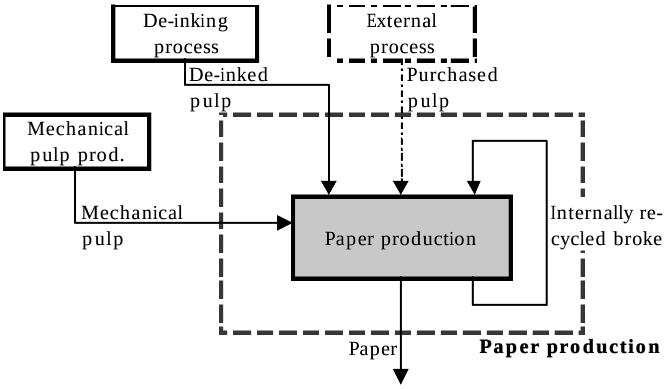

Figure 24
Hylte Mill: The alternative model for paper production and its surrounding models.

The environmental performance of each Newsprint product is calculated from the pulp composition of the different Newsprint products.

Energy production

Energy is generated from combustion in four separate boilers. Additionally, process steam is generated from the mechanical pulp production. This model includes all those points of generation, see figure 25.

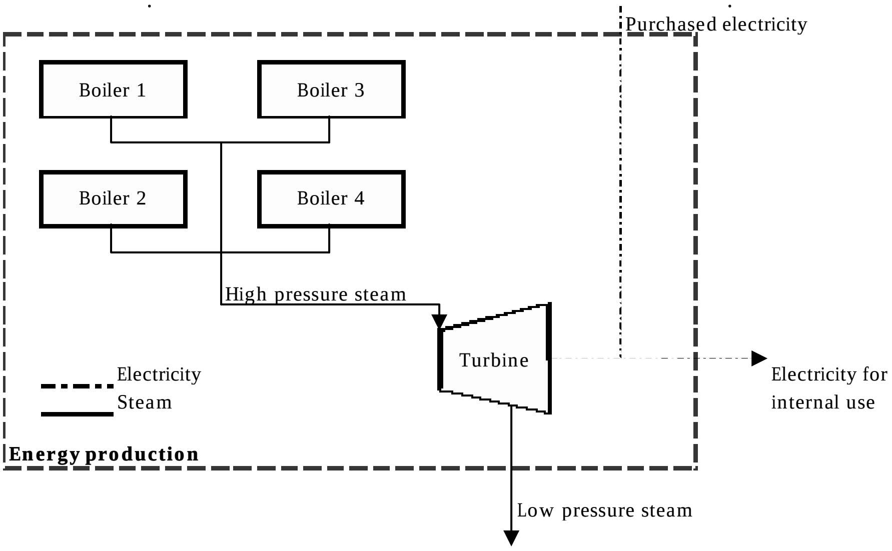

Figure 25
Hylte Mill: The alternative model for energy production.

Table 12
Energy production at the Hylte Mill: Description of relevant flows regarding allocation methods in the alternative model.

	Description
Low pressure steam	The low pressure steam is measured in MJ and has an internally set price (SEK/MJ).
Electricity	The electricity for internal use is a mixture of internally produced electricity and purchased electricity. It is measured in kWh and has a market related price (SEK/kWh).
Hot water for district heating	Spare hot water from the internal circulation is exchanged with the municipal district heating net. The hot water is measured in MJ and a contract with the customer regulates the price (SEK/MJ).

Suggested allocation method

Different allocation approaches are evaluated in appendix F. The approach including turbine efficiency is recommended for the allocation between low pressure steam and internally produced electricity. The hot water for district heating is facilitated by surplus heat, which is a close-to-waste product. The contracted price for the hot water covers the installation costs to the municipal district heating net. Therefore, no allocation is performed for the hot water for district heating

Wastewater treatment

Sufficient measurements are not conducted to support separate sub-processes' contribution to the purified wastewater emissions.

Suggested allocation method

All Newsprint products carry equal emissions to water. The allocation is based on the weight (kg) of the Newsprint products.

Alternative allocation method

If more detailed measurements on the content of the waste water flows were conducted, a similar model as that described for the Skoghall Mill (section 4.1.3) can be used.

4.3 Skutskär Mill

4.3.1 Production site and products

In this section the production site and its products are presented (step 1 of the methodology). Skutskär Mill produces bleached long and short fibre kraft pulp and bleached fluff pulp (Skutskär Mill, 2001). The mill is located at the Baltic Sea some 15 km south of Gävle in Sweden. The production site supplies many internal paper mills within the Stora Enso group and also external customers with elementary chlorine free (ECF) pulps, see figure 26. A process flowchart of the Skutskär Mill is presented in figure 27.

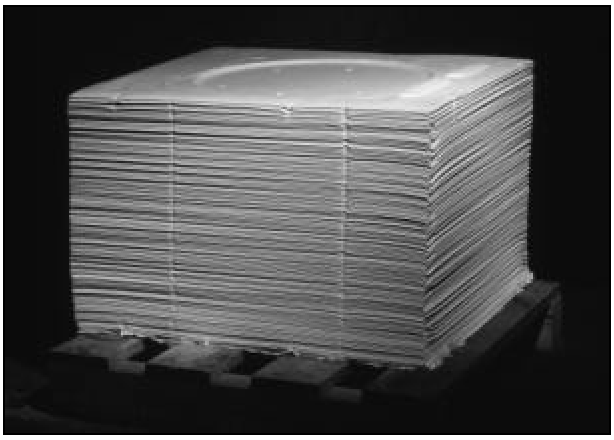

Figure 26
Example of product from the Skutskär Mill.

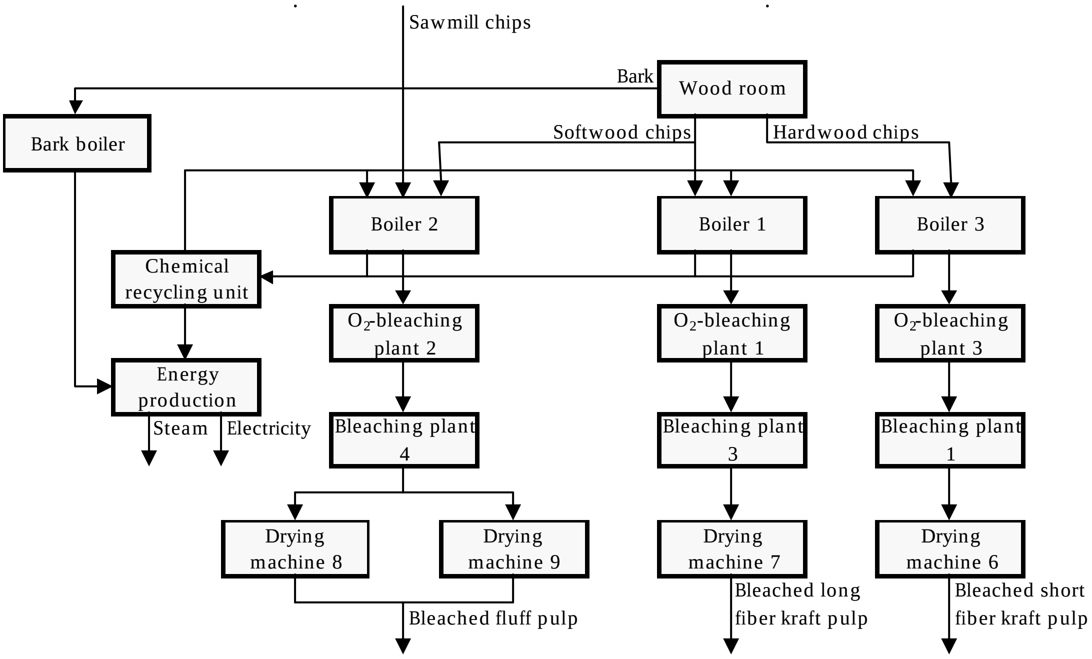

Figure 27
Process flowchart of the Skutskär Mill.

Previously, there has been no model for calculation of product specific environmental data at the Skutskär mill. However there is an internal request to establish a model that enables calculations of product group specific data (bleached fluff pulp, bleached long fibre kraft pulp and bleached short fibre kraft pulp) and identification of a production line's or a specific process step's contribution to the potential environmental impacts.

Below a number of important departments of the Skutskär Mill are presented. The Skutskär Mill has three production lines that use some common process steps, e.g. wood room, chemical recycling unit and wastewater treatment.

Wood room

In the wood room the round wood is debarks and chopped into chips. Hardwood and softwood is processed in parallel. However, it is not possible to separate emission flows or energy consumption.

Pulp line, Bleached fluff pulp

This production line consists of the following sub-processes:

- Boiler 2
  Softwood chip from the wood room and purchased sawmill chips are feed into the boiler where unbleached fluff pulp is produced. The boiling liquor is recycled in the production site's common chemical recycling unit.
- Oxygen bleaching plant 2
  The unbleached fluff pulp is first bleached in a separate step using oxygen. Pre-bleached pulp is produced.
- Bleaching plant 4
  In this second bleaching step, the pulp is treated in a number of bleaching sequences to its full brightness.
- Drying machines 8 and 9
  Before delivery the pulp is dried and cut into sheets in two parallel processes.

Pulp line, Bleached long fibre kraft pulp

This production line consists of the following sub-processes:

- Boiler 1
  Softwood chip from the wood room is feed into the boiler where unbleached long fibre kraft pulp is produced. The boiling liquor is recycled in the chemical recycling common to the whole unit production site.
- Oxygen bleaching plant 1
  The unbleached long fibre kraft pulp is first bleached in a separate step using oxygen. Pre-bleached pulp is produced.
- Bleaching plant 3
  In this second bleaching step, the pulp is treated in a number of bleaching sequences to its full brightness.
- Drying machines 7
  Before delivery the pulp is dried and cut into sheets.

Pulp line, Bleached short fibre kraft pulp

This production line consists of the following sub-processes:

- Boiler 3
  Hardwood chip from the wood room is feed into the boiler where unbleached short fibre kraft pulp is produced. The boiling liquor is recycled in the chemical recycling unit common to the whole production site common.
- Oxygen bleaching plant 3
  The unbleached short fibre kraft pulp is first bleached in a separate step using oxygen. Pre-bleached pulp is produced.
- Bleaching plant 1
  In this second bleaching step, the pulp is treated in a number of bleaching sequences to its full brightness.
- Drying machines 6
  Before delivery the pulp is dried and cut into sheets.

Chemical recycling unit

The chemical recycling unit at the Skutskär mill consists of evaporation, recovery boilers, lime kilns etc. The boiling liquors from boilers 1-3 are jointly treated and recycled. High pressure steam from the recovery boilers is delivered to the energy production unit.

Bark boiler

Bark from the wood room is incinerated in the bark boiler to generate high pressure steam to the energy production unit.

Energy production unit

High pressure steam from the recovery boilers and the bark boiler is reduced over turbines to generate electricity and steam of lower pressures.

4.3.2 Model of the technical system

In this section a model of the technical system is presented (step 2 of the methodology). A model that corresponds to the purposes specified in the section above would include the structure presented in figure 28. Later this proposed model could be refined to distinguish yet more sub-processes.

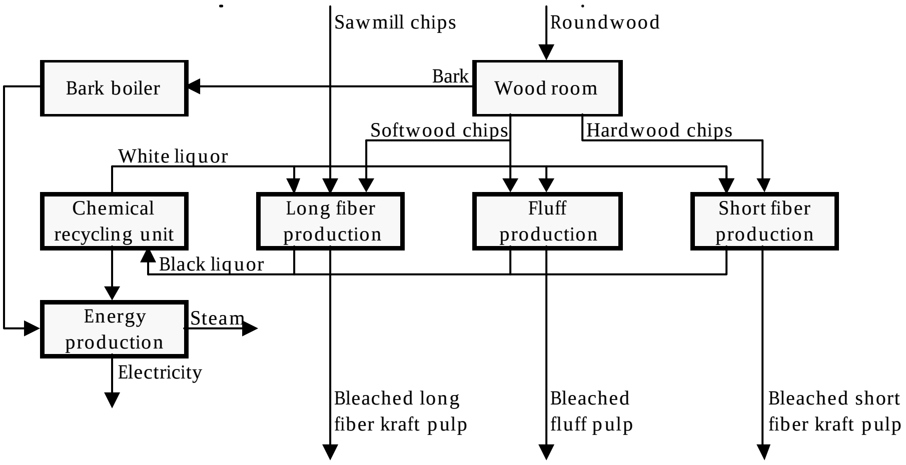

Figure 28
Structure of model for product related environmental data at the Skutskär Mill.

Each sub-process causing an allocation situation is identified below.

4.3.3 The sub-process's function and relevant flows

In this section steps 3-6 of the methodology are dealt with. Firstly each identified sub-process's function and relevant in- and outflows are presented. Secondly the relevant flows and their proportion on which it would be possible to base an allocation upon are described. The possibility to avoid allocation through further sub-division is also discussed. A suggested allocation method is recommended for each relevant sub-process. These steps are repeated for each identified sub-process. In section 5 these suggested allocation methods are analysed further.

Wood room

Figure 29 illustrates the multi output functionality of the wood room. The measurements on site do not allow a further separation of e.g. a hardwood wood room and a softwood wood room. Bark is generated as a co-product and used as an internal bio fuel. The relevant flows of the wood room are described in table 13.

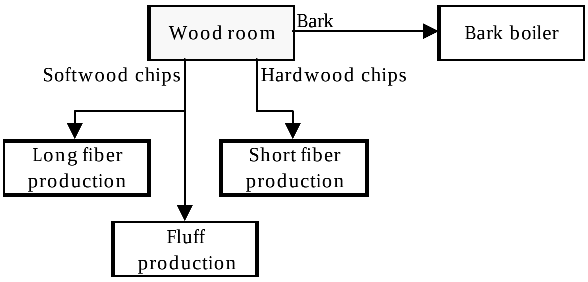

Figure 29
Skutskär Mill: The model for wood room and its surrounding models.

Table 13
Wood room at the Skutskär Mill: Description of relevant flows regarding allocation methods.

	Description
Hardwood and softwood chips	The hardwood and softwood chips are measured separately in m^3sub. The production site's measurement system does not facilitate a separation of in- and outputs related to each type of chip. Therefore both types of chips must be given equal environmental load.
Bark	The volume of the bark is an irrelevant parameter since the energy content of the bark is very dependant on its dry content. The bark is therefore measured as the energy generated (in MJ) after the combustion of the bark. The contribution of bark to the total energy generation, excluding electricity, is about 0,01% (Skutskär Mill, 2001). Therefore the bark is considered as a product without environmental load.

Suggested allocation method

The hardwood and softwood chips carry equally (based on m^3sub) all environmental aspects of the wood room. The bark carries none.

Long fibre, Short fibre and Fluff production

The three sub-processes; Long fibre production, Short fibre production and Fluff production are all schematically illustrated in figure 30. As sub-processes they can be illustrated in the same manner, but they need to be dealt with separately when the model is assembled (regarding flows etc.). The flows relevant for allocation are described in table 14.

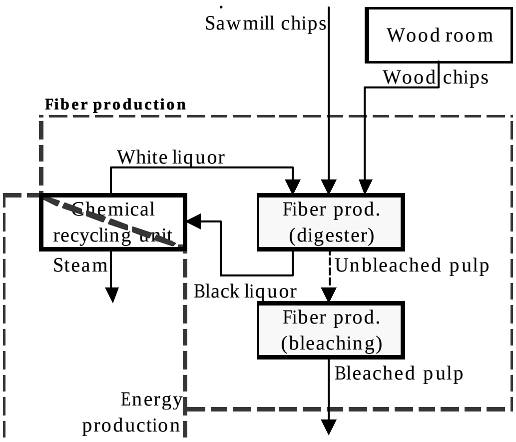

Figure 30
Skutskär Mill: The model for fibre production (Long fibre production, Short fibre production and Fluff production) and its surrounding models.

Table 14
Fibre production at the Skutskär Mill: Description of relevant flows regarding allocation methods.

	Description
Bleached pulp	The bleached pulp is the main product of the sub-process and is measured in kg. It also has an internally set price (SEK/kg).
Black liquor	The flow of black liquor is not measured. Instead the sulphur content and the alkalinity in the digester (fibre production) are controlled by the inflow of white liquor (which is the recycled product of black liquor). To solve this allocation problem, the chemical recycling part of the chemical recycling unit is theoretically separated from the energy generation part. When the chemical recycling part is added to the fibre production the black/white liquor flows become an internal loop, for which allocation is not necessary. All environmental aspects at the chemical recycling unit except emissions to air are thereby added to the fibre production in proportion to each digester's (fibre production) production. Emissions to air, ashes and other solid waste and fuels for start-ups are theoretically transferred to the energy production. Please refer to the Chemical recycling unit below for more details on this allocation.

<u>Suggested allocation method</u>

All environmental aspects of the fibre production are allocated to the bleached pulp. Additionally the environmental aspects of the chemical recycling part of the chemical recycling unit are added to the bleached pulp in proportion to each digester's production capacity. This approach is similar to the one presented for the Skoghall Mill (section 4.1.3).

Chemical recycling unit

The chemical recycling unit (see figure 31) produces both white liquor and high pressure steam from the black liquor supplied from the fibre production. This chemical recycling unit differs slightly from e.g. the one at the Skoghall Mill in the sense that it recycles liquor to/from three separate digesters. Similar situations can be recognized at other production sites e.g. Korsnäs and Billerud Gruvön. The energy content of black liquor from softwood and hardwood might differ, but this cannot be handled in this model due to insufficient measurements. The relevant flows of the chemical recycling unit are described in table 15.

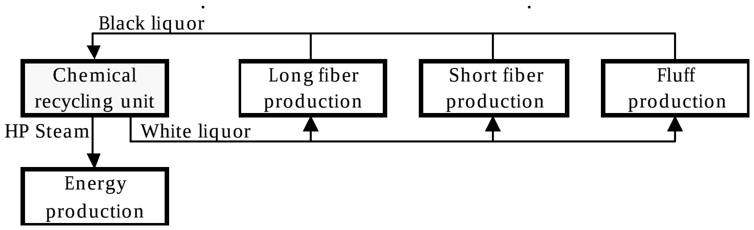

Figure 31
Skutskär Mill: The model for the chemical recycling unit and its surrounding models.

Table 15
The chemical recycling at the Skutskär Mill: Description of relevant flows regarding allocation methods.

	Description
High pressure steam	The high pressure steam is generated from the combustion of the black liquor. All emissions to air, ashes and other solid waste and fuels for start-ups are allocated to the high pressure steam.
White liquor	The flow of white liquor is not measured. The chemical recycling part is allocated to the bleached pulp according to fibre production above.

Suggested allocation method

High pressure steam carries the emissions to air, waste and supplementary fuels for start-ups. All other environmental aspects are allocated to the white liquor and thereby to the bleached pulp. This method is further presented in a similar case for the Skoghall Mill (kraft pulping sub-process, section 4.1.3).

Alternative allocation method

In the Skoghall Mill case alternative allocation methods are also presented.

Energy production

The energy production unit is illustrated in figure 32. The flows relevant for allocation are described in table 16.

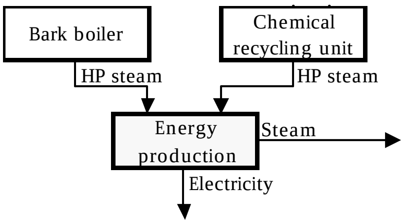

Figure 32
Skutskär Mill: The model for energy production and its surrounding models.

Table 16
Energy production at the Skutskär Mill: Description of relevant flows regarding allocation methods.

	Description
Steam	The steam is measured in MJ produced energy.
Electricity	The electricity is measured in kWh produced energy. Though MJ and kWh can be converted to each other electricity has a higher quality (exergy) than steam and allocation just based on generated energy would not justice to these differences in quality.
Hot water for district heating	Spare heat is exchanged with the municipal district heating system. The heat is measured in MJ and has a contracted price (SEK/MJ).

Suggested allocation method
Steams and electricity: Three different allocation bases are evaluated in appendix F. The turbine efficiency approach is recommended from those. When using the turbine efficiency, account is taken to the energy content of the steams and the internally produced electricity, but also to the turbine's efficiency. The loss in the turbine is subtracted from the energy generated as electricity, which results in a higher allocation factor for the internally produced electricity. This reflects the general opinion that the energy in electricity has higher quality than that in steam.
Hot water for district heating: No allocation is performed on the hot water for district heating, due to it is facilitated by spare heat that is exchanged with the municipal district heating net.
Alternative allocation method
In cases where the internally produced electricity is in focus, the exergy approach should be preferred as a basis for allocation. Allocation based on energy content only should be motivated thoroughly.

4.4 Other allocation situations in the pulp and paper industry

4.4.1 Integrated paper mill also producing market pulp

Some production sites, e.g. Korsnäs and Billerud Gruvön, produce both paper and market pulp (see figure 33). When e.g. making bench marking on market pulp these integrated pulp and paper mills may come out with a disadvantage compared to stand alone pulp production sites. This is due to two reasons; surplus steam from the pulp production is consumed by the integrated paper machine(s) and the energy consumption for drying paper is higher than for drying pulp. Using a modelling and allocation method acknowledging this problem can solve this perceived disadvantage.

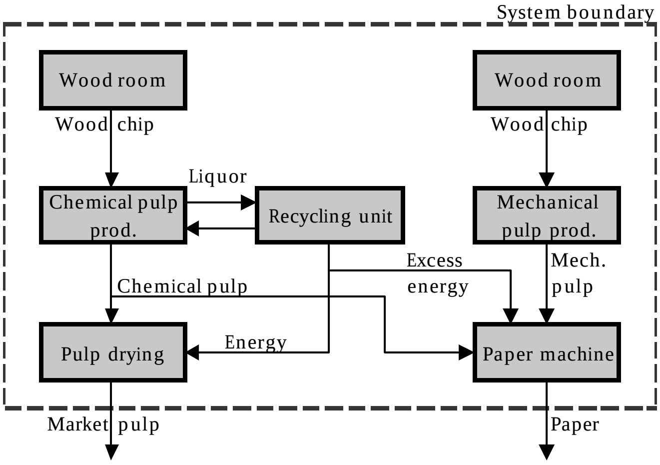

Figure 33
Example of integrated paper mill also producing market pulp.

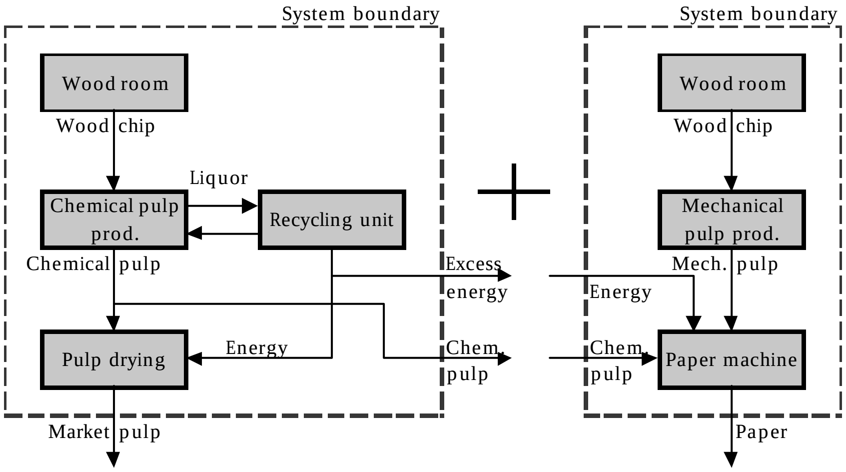

Figure 34
Proposed modelling method to avoid the perceived disadvantage for market pulp produced in an integrated paper mill.

When splitting the model in figure 33 into two models (figure 34), an allocation situation occurs that need to be dealt with. In the first sub-model (production of market pulp) excess energy and chemical pulp is also produced. In the second sub-model only paper is produced.

Table 18
Integrated paper mill also producing market pulp: Description of relevant flows regarding allocation methods.

	Description
First sub-model (production of market pulp)	The first sub-model is the part of the integrated mill that is producing market pulp (compare with figure 2c, production of market pulp).
- Market pulp	The market pulp is the main product of the sub-model. The market pulp is measured in kg and has a market price (SEK/kg).
- Excess energy	The excess energy (steam) is delivered to the second sub-model (production of paper). It is measured in MJ and has an internally set price.
- Chemical pulp	The chemical pulp is delivered to the second sub-model (production of paper). It is measured in kg and has an internally set price. Unlike the market pulp, the chemical pulp is delivered in an un-dried condition.
Second sub-model (production of paper)	The second sub-model is the part of the integrated mill that is producing paper (compare with figure 2b, unintegrated paper production).
- Paper	As presented here, no allocation is necessary for the production of paper.

Suggested allocation method

Market pulp and chemical pulp are allocated on equally by weight, but the market pulp carries all environmental aspects associated with drying, packaging etc. of the pulp. No allocation is performed on excess energy, but the amount of excess energy is from the pulp production is presented as a co-product to the market pulp.

4.5 Internal allocation situations in other industrial activities

4.5.1 LCAs on bearings

Internal allocations have been dealt with in two studied LCAs on bearings produced by SKF[1]. The production of bearings is an assembly process, though most parts are manufactures "in-house". The scope of the studies (Ekdahl, 2001 and Nilsson, 2001) were to investigate the environmental properties of two specific bearings and to identify parameters and processes causing major environmental impacts. Both LCAs were conducted as master's theses. In the first study three allocation methods were identified:

- Distribution key
  A distribution key is used when calculating the production cost of a specific product. Nobody knows the origin of the key (that was presented as 11,62% for a certain product) or what lies behind it!
- Economical value
  The price of a specific product is related to the economical value of the total production at the site.
- Number of products
  The amount of a specific product is related to total number of products produced at the site.

Remarkably, the results presented in the study may vary up to a factor 2,7 depending on which allocation method is used.

In the second study (Nilsson, 2001) only one method is used: Weight of the product.

Similarities with allocations in the pulp and paper industry

For the applications of the LCA studies above, SKF seem to prefer retrospective before prospective LCA. At least two different approaches for basing an allocation are used. The price of the product and some physical relation reflecting the production volume (weight or number of products). Both approaches correspond well to the approaches presented in the case studies of this report. Another similarity is the use of different allocation bases in different situations (Ekvall, 2000). The uncertainties concerning the distribution key make any analysis of that allocation base irrelevant.

4.5.2 French LCA Food project

The French LCA Food project was an initiative started in 1992. In a conference paper (Teulon) on the project some examples of allocation methods are presented. These include properties like mass, dried mass, fat/sugar content and economic value. The scope of the project was to introduce the French food industry to the LCA methodology by conducting some 13 case studies on food products. The examples presented in the paper show a great variety in the allocation factor depending on which basis for allocation is chosen (from 99% to 15% allocation on the main product). In the paper "partitioning will be carried out with physical allocation factors, chosen so as to reflect industrial reality" (Teulon). This means that allocation is performed based on sugar content in the example on sugar production and fat content in the example on cheese production. Tulon's results are summarised in figure 35.

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[1] SKF is an international producer of roller bearings, ball bearings etc. More information on SKF is available at www.skf.com.

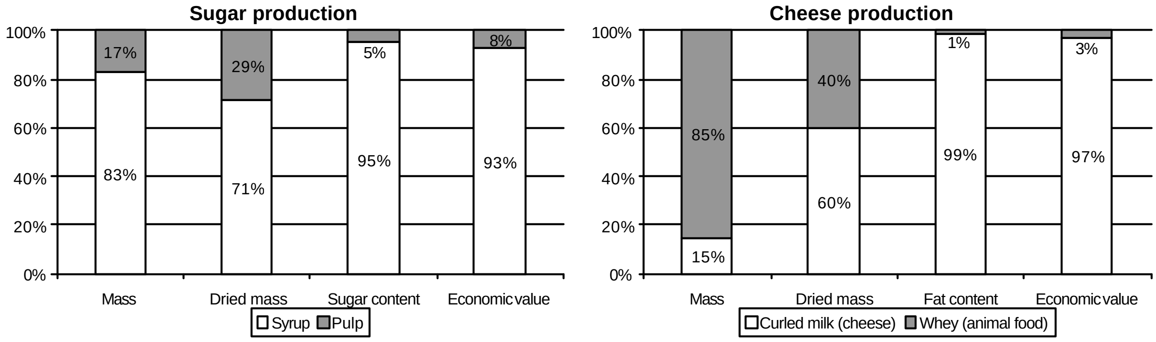

Figure 35
Effects of the allocation bases in the French LCA Food project (Teulon).

The allocation method recommended (based on the fat and sugar content respectively) result in a heavy focus of the environmental aspects on the main products of the two production systems. Further on so-called “close to waste co-products” are discussed. These are materials that once were treated as waste, but due to new environmental laws are today further processed to co-products. These “close to waste co-products” are suggested not to be allocated on (thus 100% on the main product), and only carry the environmental loads of the separate processes of transforming them from waste to a saleable product.

Similarities with allocations in the pulp and paper industry

Like presented in the French LCA Food project, several characteristics of the products can be found also in the pulp and paper industry. Instead of mass, dried mass, sugar/fat content and economic value a certain type of paper product can be characterised by weight (kg), grammage (g/m^2), brightness (% ISO), printability, economic value, production cost and price (SEK/ton), etc. The problem for the pulp and paper industry is that most of the multi-product sub-processes generate products with rather different characteristics, e.g. pulp and steam (both produced in e.g. the CTMP process). Also when looking at the entire production site, only characteristics like weight and economic value are common for the main products and the co-products (e.g. tall oil and turpentine).

4.5.3 SIK’s LCI on semi-hard cheese

In a LCI on semi-hard cheese (Berlin, 2001) several allocation problems occur. The goal of the study was to assess the environmental impacts of a specific semi-hard cheese. The focus of the study was the dairy and the activities the dairy controls. Some relevant examples of how the allocation was conducted in the study are presented below:

- At the cheese dairy, economical allocation is used to solve the multi-output situation. Four kinds of cheese along with, cream, skim milk, milk powder, whey powder and whey are produced.
- At farm level economic allocation is used to distinguish milk production from meat production.

In the production of the ingredients to the cheese, weight allocation is used to distinguish environmental aspects related to the production to each ingredient and it’s co-products. However, in the production of one of the ingredients, surplus energy is generated. In this case all in- and outflows are allocated to the production of the ingredient and none to the energy, since the reason for production is to produce the ingredient.

Similarities with allocations in the pulp and paper industry

Like the LCI study of semi-hard cheese, this report focuses on the activities that are controlled by the pulp and paper production site. When using LCI data of raw materials and additives, information provided by the suppliers must be relied upon. Using different allocation bases for different allocation situations along the production chain is commonly done also in the pulp and paper industry and e.g. in the SKF studies presented above. Economical allocation is motivated by the reason for the existence of the dairy is to be profitable.

4.5.4 Summary of literature studies

Each of the literature studies have had the same scope; to evaluate the environmental performance of a product and to identify sub-processes that are the most important contributors to the potential environmental impact. For these applications retrospective LCA has been chosen, and hence allocation instead of system expansion. Like suggested in this report, different allocation bases are used to solve different allocation problems. Physical relations and economical value are most commonly used as allocation bases. Close-to-waste products (in the pulp and paper industry; e.g. heat to district heating) are not allocated on since their economical value is estimated to zero.

5 Analysis and recommendations of BAP

In the case studies presented in section 4 different bases for allocation are suggested for different situations. Finding one base for all allocations has not been feasible. Also when a similar allocation situation occurs at different production sites, different bases for allocation may be needed to reflect local deviations in process technology, demands from stakeholders etc. The case studies present bases for allocation reflecting the need for feasible (or even simple) and acceptable calculation methods.

5.1 Stakeholders' demands on allocation

Different stakeholders require environmental data of different formats (Svending, 2001). This includes presentation of different parameters, emphasis on different phases of a life cycle using different system boundaries, requiring allocations to be performed in a specific manner, etc. In the section below the different actors perceived requirements on internal allocations are presented.

5.1.1 Authorities

Integrated Product Policy (IPP) is the regulation focusing on products' life cycles rather than on production sites, seeking to minimise the environmental impacts. IPP is a European approach that will be adopted by the national Environmental Protection Agencies (EPAs). IPP includes all steps of a product, from product design via raw material extraction and production to waste management. In the context of IPP, product related environmental data is needed for e.g. product development and environmental communication. For example, the EU-Flower and Paper Profile are described below.

5.1.2 Customers

When communicating the environmental performance of a product, labels and declarations related to the ISO 14020-series (Environmental labels – type I, Self-declarations – type II and Environmental declarations – type III) are generally used. In other cases customers have developed their own questionnaires incorporating specific parts of the product's life cycle.

EU-Flower

The criteria for the European eco-label for copying and graphic papers was latest revised in May 2002. The revised criteria (EU-Flower, 2002) contain no requirements on how internal allocation at a production site shall be performed. The EU-Flower is still an uncommon eco-label for pulp and paper products.

Figure 36
The EU-Flower logotype.

The Nordic Swan

Today there exist several Swan criteria documents for different types of paper products, e.g. packaging paper and printing paper (Nordic Swan, 2002). Since the introduction of the Paper Profile (presented below), the number of licenses for these criteria have dropped. In the criteria document for printing paper (Nordic Ecolabelling, 2002) no methods for internal allocation are proposed except for the calculations based on the product's pulp composition.

Figure 36
The Nordic Swan logotype.

Paper Profile

Paper Profile is a voluntary environmental declaration developed by the major European paper industries. In the instructions for Paper Profile (Paper Profile, 2001) allocation is briefly dealt with. This is described in the following:

- Allocation within a production site must add up to 100% of the total emission load.
- Allocation must be based on a cause-effect approach.
- No allocation is performed on co-products.

Questionnaires

Special questionnaires have been sent out from separate customers. These have varied in scope, but they usually focus on environmental aspects of the production phase of a specific paper's life cycle. If dealt with at all, allocation procedures are only mentioned in general terms.

None of the stakeholders within authorities and customers give specific instructions on how internal allocation shall be handled. Instead industry needs to develop guidelines for these issues that include how allocation shall be handled to answer to different stakeholders.

5.1.3 Internal stakeholders

Internal stakeholders are here defined as the users of environmental data for e.g. product development, continuous improvements, policy making, other decision making. To supply data to these applications local routines are commonly established at the production sites. Procedures for allocation must be flexible enough to meet local requirements due to the production sites infrastructure and requests from stakeholders. The allocation procedures also need to be coordinated within a group (e.g. Stora Enso) or even within a business branch to enhance stakeholders' credibility of the generated environmental data.

5.2 Other allocation bases

5.2.1 Simplifications instead of allocation

In the case studies presented in section 4, some simplified allocation approaches are presented. These simplifications include e.g. not allocating on external and internal co-products. The argumentation for doing so is commonly that these co-products are insignificant in the sense that the main product of a sub-process is the reason for the initial set-up of that sub-process. Historically most of the co-products have been regarded as waste, e.g. bark was landfilled until it was environmentally and economically motivated to incinerate bark for energy production.

In many of these allocation situations the causal relationships between the different products are possible to identify, but difficult to base an allocation on. An example of such relationship can be kg pulp compared to MJ steam in the mechanical pulping process. In other situations these relationships can be difficult to identify due to lack of measuring equipment, e.g. the amount of black liquor (kg black liquor/kg pulp) generated in the digester. In the case studies these allocation situations have been pragmatically solved to find feasible and acceptable allocation bases rather than finding solutions that are perfectly justifiable. A common approach is to allocate 100% to the main product of a sub-process.

5.2.2 Economical value as allocation base

Today however, almost all flows that earlier were considered as non-useful are used in some way. Chemical co-products are refined and sold internally or externally, energy from hot water is reused through heat exchangers, and many waste fractions (with decent heat values) are incinerated to generate steam. From a LCA practitioner’s point of view it would therefore be relevant to find allocation bases that reflect these values of the co-products. But, when doing this it is needed to step aside from the physically oriented approach and use another relationship: Economic value. The economic value of a product is usually set based on two different approaches; production cost and market price.

Production cost/Internally set price

The internally set price is based on the production cost, which is calculated from the running costs (costs for pulp wood, supply chemicals, energy etc.) and the fixed costs (depreciation of production machinery, building and other investments). This internally set price is used for internal invoicing between the different departments at the production site. Within an industrial group like Stora Enso it is common to distribute depreciation costs from less profitable units to more profitable ones. The production cost (and thereby the internally set price) is normally classified information that for competitive reasons should not reach competitors or customers. These transactions and the sensitivity of spreading make the internally set price unreliable as a base for allocation.

Market price

The market price of the pulp and paper industry’s products is commonly sensitive to the international business cycle. To illustrate this the list price of Northern Bleached Softwood Kraft is compared with the Norscan is the north American and Scandinavian pulp stock inventory. The data is taken from Pulpex, a European benchmarking place for pulp prices.

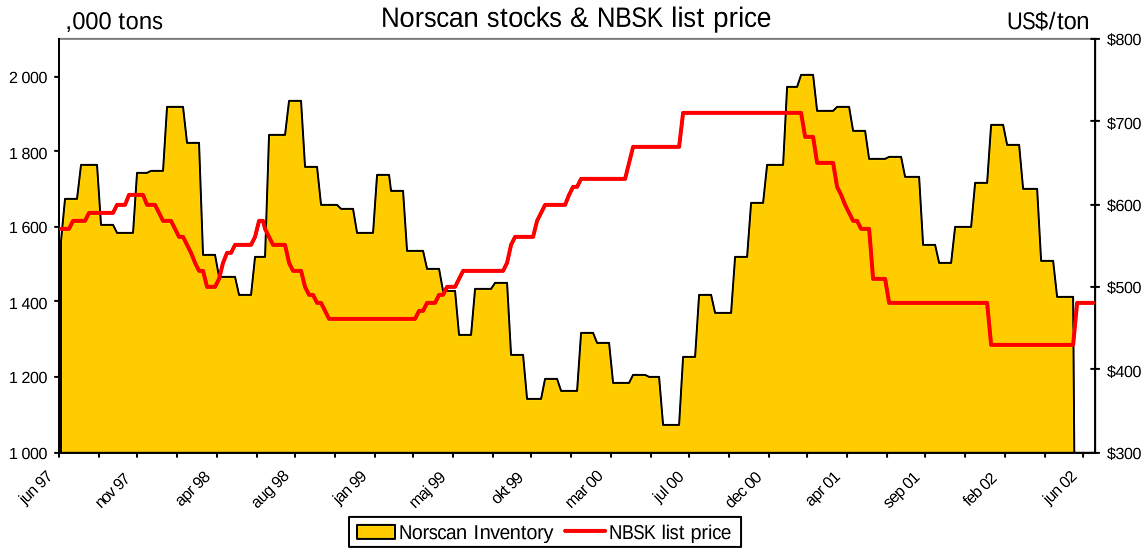

Figure 37
Norscan pulp stock inventory and Northern Bleached Softwood Kraft pulp (NBSK) price variations over 5 years time. Source: www.Pulpex.com.

Figure 37 shows that the pulp price dropped some 60% in less than two years, and is currently showing a tendency to increase again.

Economical value as a base for allocation is difficult to use due to:

- Fluctuations in the market price for pulp and paper products.
- Restricted accessibility and distributed depreciation costs in the internally set price.
- Difficulty to compare market price and the internally set price.

6 Glossary

AOX	Adsorbable organic halogens.
COD	Chemical oxygen demand.
CPM	Competence center in environmental assessment of product and material systems at Chalmers university of technology.
CTMP	Chemi-thermo mechanical pulp.
ECF	Elementary chlorine free. Pulp bleaching process involving no chlorine gas (Cl_2).
Effective alkali	An expression for the concentration of alkaline components in alkaline cooking liquor.
EMAS	Eco-management and auditing scheme.
FSC	Forest stewardship council.
IPP	Life cycle assessment.
m^3sub	Cubic meters solid under bark, common measure for pulpwood.
N-tot	Total emission to water of Nitrogen containing compounds.
P-tot	Total emission to water of Phosphorus containing compounds.
SEK	Swedish Krona, the Swedish currency.
SS	Suspended solids.
SSVL	The Swedish forest industries environmental research foundation (in Swedish: Siftelsen Skogsindustriernas Vatten- och Luftvårdsforskning).
Sulphidity	A property of alkaline cooking liquors which indicated the relative content of hydrogen sulphide.
TCF	Totally chlorine free. Pulp bleaching process involving no chlorine gas (Cl_2) or chlorine dioxide (ClO_2).
TMP	Thermo-mechanical pulp.
WWT	Waste water treatment.

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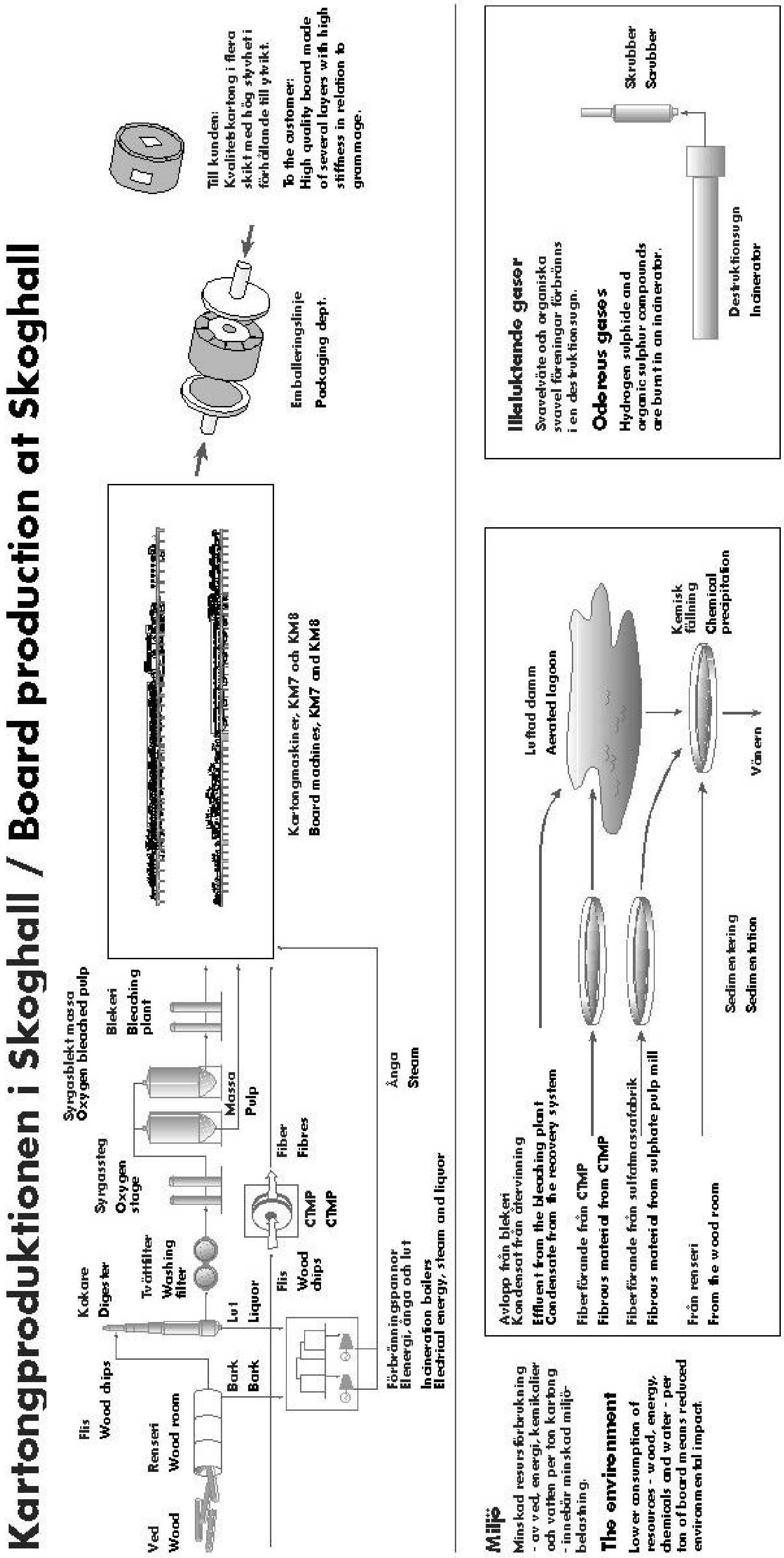
Appendix A
Process flowchart of the Skoghall Mill.



Till kunden:
Kvalitetskartong i flera skikt med hög styvhet i förhållande till ytvikt.

To the customer:
High quality board made of several layers with high stiffness in relation to grammage.

Miljö
Minskad resursförbrukning - av ved, energi, kemikalier och vatten per ton kartong - innebär minskad miljöbelastning.

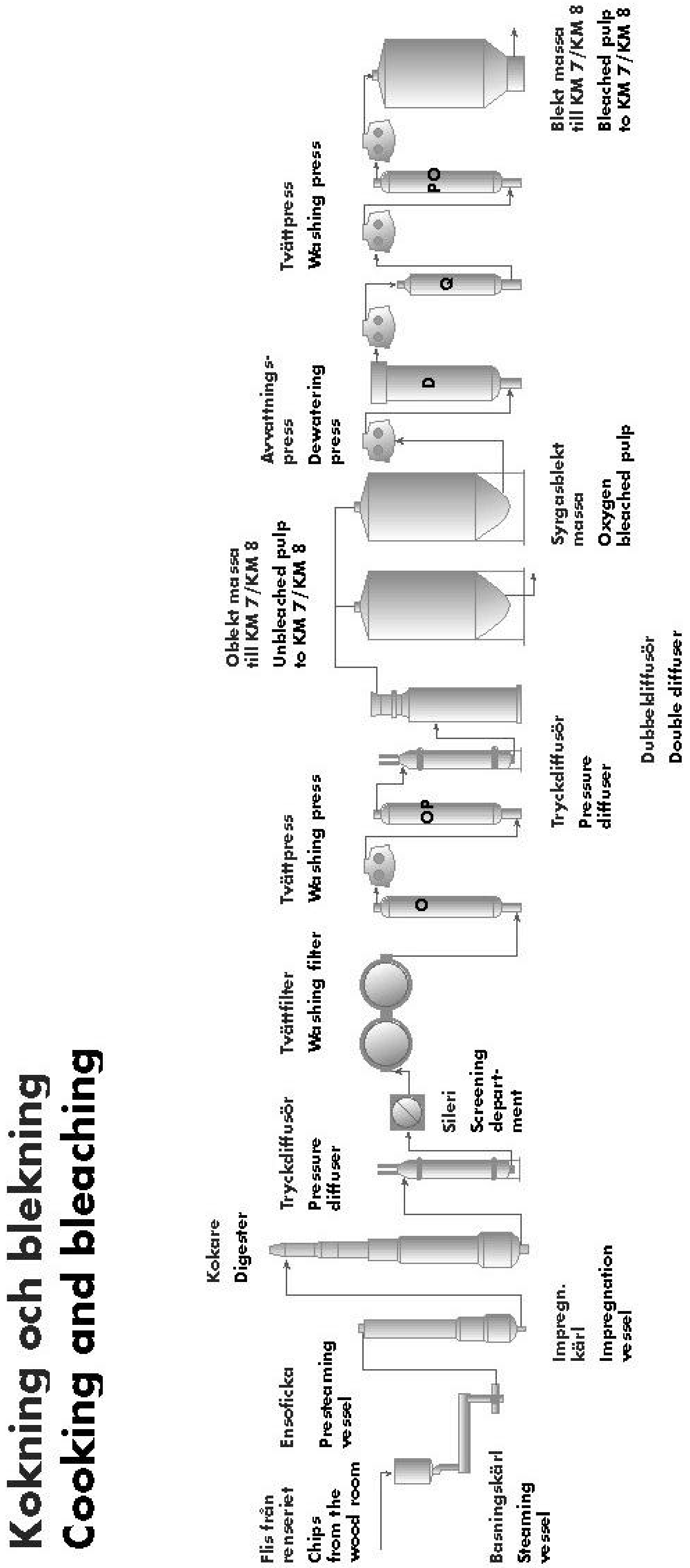
The environment
Lower consumption of resources - wood, energy, chemicals and water - per ton of board means reduced environmental impact.

Illaluktande gaser
Svavelväte och organiska svavelföreningar förbränns i en destruktionsugn.

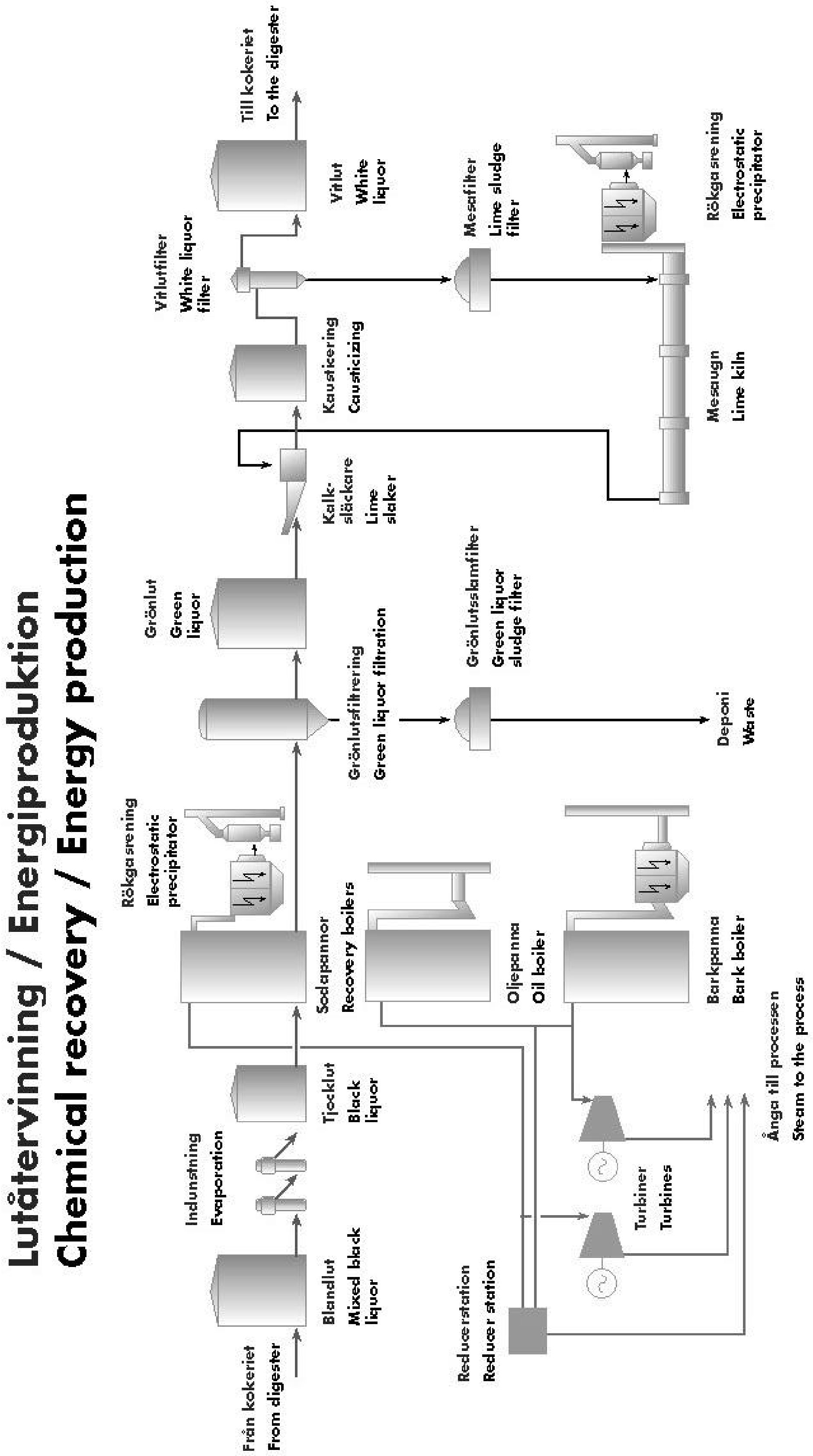
Odorous gases
Hydrogen sulphide and organic sulphur compounds are burnt in an incinerator.

Appendix B

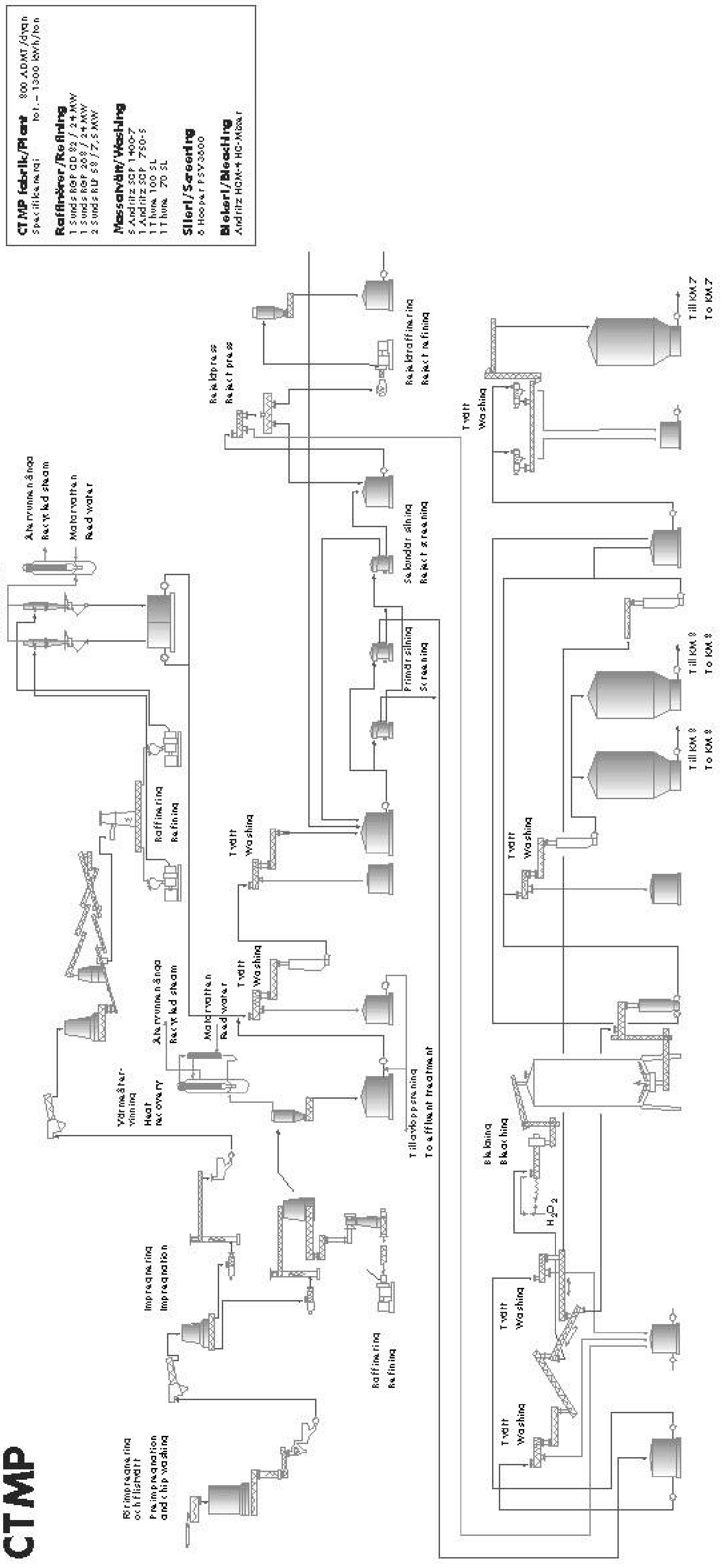
Process flowchart of the kraft pulp cooking and bleaching operations at the Skoghall Mill. The flows of liquor are not included.



Appendix C
Process flowchart of the chemical recycling unit and part of the energy production at the Skoghall Mill.



Appendix D
Process flowchart of the CTMP production at the Skoghall Mill.



Appendix E
Example of product specification from the Skoghall Mill.

Kvalitetsspecifikation, mälderi KM 8 Kvalitet: 810011

Specifikationstyp:	Grundinställning	**Reviderad datum:**	990226
Ytvikt:	229 g/m²	**Ersätter:**	981119
Anmärkning:	Duplex HSI 230 mN	**Specifikation daterad:**	961202
Övrigt:		**Signatur:**	

SKIKTSAMMANSÄTTNING

	Massaslag	**Kvot (%)**	**Malgrad (SR)**		**pH (viragrop)**			**Fyllm. Ansilex**		
			min	Rikt	Min	Rikt	Max	Min	Rikt	Max
Ytskikt	Bl eukalyptus	x	x	x	x	x	x	x	x	x
x g/m²	Bl Barr	x		x						
	Övrigt: Max x% kortfiber									
Centerskikt	CTMP	x			x	x	x			
x g/m²	Armering (utskott)	x		x						
	Utskott	x		x						
	Utfyllnad	x								
	Övrigt: Om låg Z-styrka öka armeringsutskott till x%									
Bakskikt	Obl barr	x		x	x	x	x			
x g/m²	Övrigt:									
	pH på inkommande massor:		Blekt: x			Oblekt: x				

KEMIKALIETILLSATSER

	Neutrallim	**Hartslim**	**Alun**	**Stärkelse**	**Våtstyrkemedel**
Konc (%)	Handelsvara	Handelsvara	x	x	Handelsvara
Dosering	kg/ton	kg/ton	kg/ton	tidig kg/ton sen	kg/ton
Ytskikt	x	x	x	x + x	x
Centerskikt	x	x	x	x + x	x
Bakskikt	x	x	x	x + x	x

	BMA / Bentonit	**Polymer**	**DTPA**	**Sulfit**	**Bikarbonat**
Konc (%)	x / x	x	Handelsvara	x	x
Dosering	kg/ton	kg/ton	kg/ton	kg/ton	kg/ton
Ytskikt	x / x	x	x	x	x
CS1	x / x	x	x	x	x
CS2	x / x	x	x	x	x
CS3	x / x	x	x	x	x
Bakskikt	x / x	x	x	x	x

Appendix F
Bases for energy allocation

At many production sites, the energy production comprises both the production of steam and electricity from high-pressure steam as illustrated in figure F1. Usually more than one turbine is connected to each other in a series producing more than one steam products (different pressures).

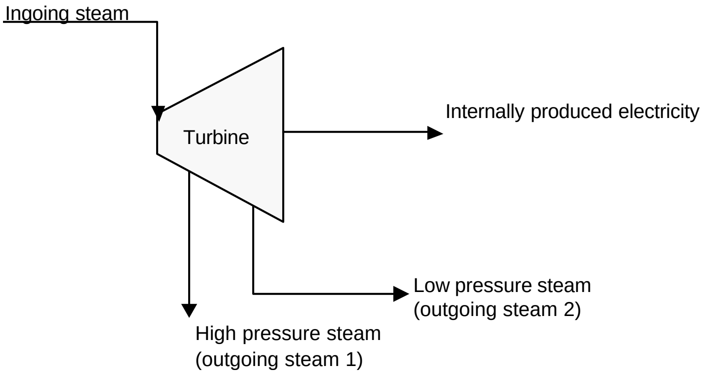


Figure F1
Co-production of steam and electricity.

This situation has been described in the case studies for the Skoghall Mill and the Skutskär Mill. In this appendix, three different bases for allocation are presented and compared: Gibb's free energy, energy content and turbine efficiency. Note that the figures are typical for the production site and that they represent only a part of the total energy production.

Assumptions

Table F1 summarizes the assumptions made in appendix F.

Table F1
Input of typical values from the case studies for testing allocation based on Gibb's free energy.

	Unit	*Skoghall Mill*	*Skutskär Mill*	*Comment*
Turbine efficiency	%	81	80	Typical site value
Turbine's days of operation	days	352	355	Typical site value
Pressure of the reference vapour	MPa	0,1	0,1	Normal atmospheric pressure
Temperature of the reference vapour	°C	5	5	Average temperature

Abbreviations

E_{out} / Ex_{out}	Sum of outgoing energy/exergy (steam + electricity) from the turbine
E_{steam}	Sum of outgoing steam energy from the turbine

Energy content

The perhaps most simple base for allocation is the energy content of the products. This base does however not reflect the differences in electric and steam energy. Typical values taken from the case studies are presented in table F2.

Table F2
Input of typical values from the case studies for testing allocation based on the energy content.

Parameter	*Unit*	*Skoghall Mill*	*Skutskär Mill*	*Comment*
Low pressure steam (outgoing steam 1)				
Pressure, $P_{LP\ steam}$	MPa	0,28	0,344	Mill representative data
Temperature, $T_{LP\ steam}$	°C	168	170	Mill representative data
Enthalpy, $h_{LP\ steam}$	kJ/kg	2800	2801	Taken from table for the corresponding P and T
Steam flow, $Q_{LP\ steam}$	ton/year	669082	2973480	Mill representative data
Energy, $E_{LP\ steam}$	GJ/year	1873552	8327925	$E_{LP\ steam}=h_{LP\ steam}*Q_{LP\ steam}/1000$
High pressure steam (outgoing steam 2)				
Pressure, $P_{HP\ steam}$	MPa	0,96	1,11	Mill representative data
Temperature, $T_{HP\ steam}$	°C	210	201	Mill representative data
Enthalpy, $h_{HP\ steam}$	kJ/kg	2854	2824	Taken from table for the corresponding P and T
Steam flow, $Q_{HP\ steam}$	ton/year	547430	1013880	Mill representative data
Energy, $E_{HP\ steam}$	GJ/year	1562202	2863027	$E_{HP\ steam}=h_{HP\ steam}*Q_{HP\ steam}/1000$
Internally prod. electricity				
Energy, E_{el}	MWh/year	27927	374028	Mill representative data
Energy, E_{el}	GJ/year	100537	1346501	1 MWh = 3,6 GJ
Allocation factor, A				
Low pressure steam	%	53%	66%	$A_{LP\ steam}=E_{LP\ steam}/(E_{out})$
High pressure steam	%	44%	23%	$A_{HP\ steam}=E_{HP\ steam}/(E_{out})$
Int. prod. electricity	%	3%	11%	$A_{el}=E_{el}/(E_{out})$

Turbine efficiency

Turbine efficiency is an approach similar to the energy content, but here the losses in the turbines (friction energy etc.) are taken into account. These losses are perceived to origin from the electricity generation and are therefore transferred to the internally produced electricity. Table F3 presents typical values from the case studies.

Table F3
Input values from the case studies for testing allocation based on the turbine efficiency.

Parameter	*Unit*	*Skoghall Mill*	*Skutskär Mill*	*Comment*
Low pressure steam (outgoing steam 1)				
Energy, $E_{LP\ steam}$	GJ/year	1873552	8327925	Calculated in table F2
High pressure steam (outgoing steam 2)				
Energy, $E_{HP\ steam}$	GJ/year	1562202	2863027	Calculated in table F2
Internally prod. electricity				
Energy, E_{el}	MWh/year	27927	374028	Mill representative data
Energy, E_{el}	GJ/year	100537	1346501	1 MWh = 3,6 GJ
Turbine efficiency, h	%	81%	80%	Mill representative data
Allocation factor, A				
Low pressure steam	%	53%	65%	$A_{LP\ steam}=E_{LP\ steam}/\ (E_{steam}+E_{el}/\eta)$
High pressure steam	%	44%	22%	$A_{HP\ steam}=E_{HP\ steam}/\ (E_{steam}+E_{el}/\eta)$
Int. prod. electricity	%	3%	13%	$A_{el}=E_{el}/\eta/(E_{steam}+E_{el}/\eta)$

Exergy

The allocation between the products (outgoing steam and internally produced electricity) is based on the exergy (also be referred to as availability) content of each product. The specific exergy (ex) of the steam is defined by Gibb's free energy:

$$ex=(h-h_0)-T_0*(s-s_0) \qquad [MJ/kg],$$

where h is the enthalpy [MJ/kg], s is the entropy [MJ/kg, K] and T_0 is the temperature [K] of the reference vapour. h_0 and s_0 are the enthalpy and entropy of the reference vapour.

The total exergy (Ex) for steam is calculated by:

$$Ex=ex*Q \qquad [MJ/year],$$

where Q is the flow of steam [kg/year]. The exergy for electricity is per definition 100% of the electricity's energy content. The exergy approach is tested in table F4 for typical values taken from the case studies.

Table F4
Input of typical values from the case studies for testing allocation based on exergy.

Parameter	*Unit*	*Skoghall Mill*	*Skutskär Mill*	*Comment*
Reference state				Estimated as saturated liquid
Pressure, P_0	MPa	0,1	0,1	Normal atmospheric pressure
Temperature, T_0	°C	5	5	Normal temperature
Enthalpy, h_0	kJ/kg	21,0	21,0	Taken from table for the corresponding P and T
Entropy, s_0	kJ/kg, °C	0,076	0,076	Taken from table for the corresponding P and T
Low pressure steam (outgoing steam 1)				
Pressure, $P_{LP\ steam}$	MPa	0,28	0,344	Mill representative data
Temperature, $T_{LP\ steam}$	°C	168	170	Mill representative data
Enthalpy, $h_{LP\ steam}$	kJ/kg	2800	2801	Taken from table for the corresponding P and T
Entropy, $s_{LP\ steam}$	kJ/kg, °C	7,202	7,115	Taken from table for the corresponding P and T
Specific exergy, $ex_{LP\ steam}$	kJ/kg	797	822	Difference between ingoing steam and outgoing steam 1
Steam flow, $Q_{LP\ steam}$	ton/year	669082	2973480	Mill representative data
Total exergy, $Ex_{LP\ steam}$	GJ/year	533323	2444019	$Ex_{LP\ steam}=ex_{LP\ steam}*Q_{LP\ steam}/1000$
High pressure steam (outgoing steam 2)				
Pressure, $P_{HP\ steam}$	MPa	0,96	1,11	Mill representative data
Temperature, $T_{HP\ steam}$	°C	210	201	Mill representative data
Enthalpy, $h_{HP\ steam}$	kJ/kg	2854	2824	Taken from table for the corresponding P and T
Entropy, $s_{HP\ steam}$	kJ/kg, °C	6,766	6,641	Taken from table for the corresponding P and T
Specific exergy, $ex_{HP\ steam}$	kJ/kg	972	977	Difference between ingoing steam and outgoing steam 2
Steam flow, $Q_{HP\ steam}$	ton/year	547430	1013880	Mill representative data
Total exergy, $Ex_{HP\ steam}$	GJ/year	532030	990303	$Ex_{HP\ steam}=ex_{HP\ steam}*Q_{HP\ steam}/1000$
Internally prod. electricity				
Energy, E_{el}	MWh/year	27927	374028	Mill representative data
Total exergy, Ex_{el}	GJ/year	100537	1346501	Exergy for electricity is 100% of the energy. 1 MWh=3,6 GJ
Allocation factor, A				
Low pressure steam	%	46%	51%	$A_{LP\ steam}=Ex_{LP\ steam}/(Ex_{out})$
High pressure steam	%	46%	21%	$A_{HP\ steam}=Ex_{HP\ steam}/(Ex_{out})$
Int. prod. electricity	%	9%	28%	$A_{el}=Ex_{el}/(Ex_{out})$

Summary and discussion

The allocation factors from the three approaches are summarized in figure F2, comparing the different approaches for each production site.

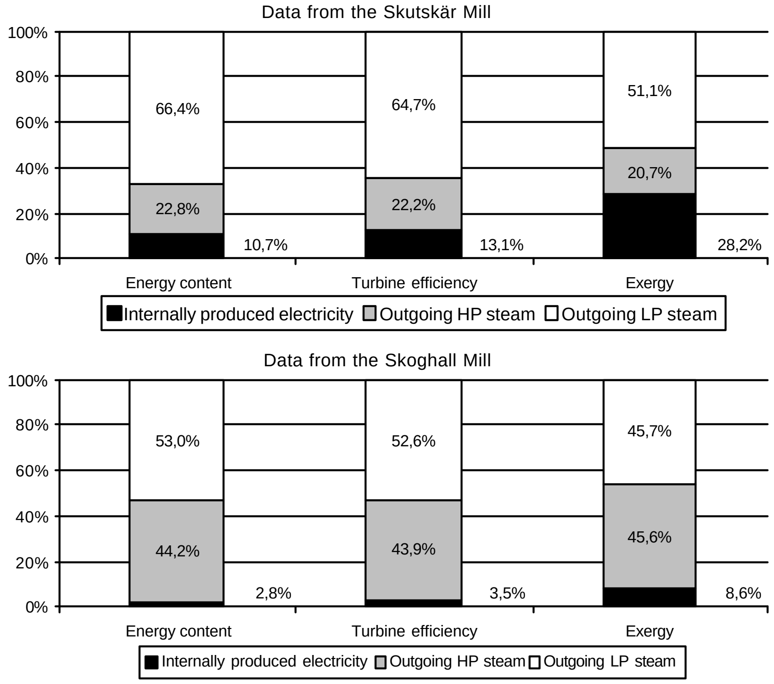


Figure F2
Charts illustrating the three allocation approaches for outgoing low and high pressure steams and internally produced electricity.

Figure F2 illustrates firstly a difference in energy production at the two case studies. At the Skoghall Mill less internally produced electricity (3% compared to 11% - calculated as energy content) than the Skutskär Mill. Further on almost the same amount of outgoing low and high pressure steam is produced at the Skoghall Mill. Comparatively more outgoing low pressure steam is produced at the Skutskär Mill (calculated as energy content). This makes the two cases not directly comparable with each other. The allocation factors for internally produced electricity (in both case studies) show an increasing trend as the base for allocation changes from energy content, via turbine efficiency to exergy. As anticipated; the turbine efficiency gives a slightly higher allocation factor for the internally produced electricity, than does the energy content base. This is due to the two allocation bases (energy content and turbine efficiency) internal relationship. Exergy results in a consequently higher allocation factor for the internally produced electricity (in these cases a factor 2,5).

From the practitioner’s point of view, the two first allocation approaches (energy content and turbine efficiency) are more easily dealt with than the exergy approach. According to the two case studies these simplified approaches can be acceptable in cases where a relatively small internal production of electricity take place. In cases where the internally produced electricity is in focus, the exergy approach should be considered, since it reflects the usefulness (or availability) of the energy in a way that the two other approaches don’t.