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HORIZON 2020 Project Nr. 693845

Technical analysis – Pulp and Paper sector (NACE C17)

WP4: Picture of efficiency projects implemented by the Industry sector-by-sector and process-by-process

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1 Introduction

Pulp and paper manufacturing and processing covers NACE Sector C17 and can be split in the following subsectors:

- C17.1 Manufacture of pulp, paper and paperboard
- C17.2 Manufacture of articles of paper and paperboard

Some paper products are covered also in NACE sector C18 (Printing and reproduction of recorded media), under the subsector C18.1 (Printing and service activities related to printing), but in terms of energy consumption and energy intensity this sector is not as relevant as C17, so this work will not consider it (C17 covers 90-98% of the total energy consumption of C17 and C18; C17.1 is very energy intensive, while C17.2 and C18 are considered non-intensive sectors).

The main products of sector C17 are pulp and paper. In particular, pulp is the "raw material" used for paper production and can be either manufactured in the same plant as paper (integrated pulp and paper plant) or in a different location and then sent as dried pulp to a paper factory.

2 Pulping processes

There are several types of pulping processes. The main ones are:

- Chemical pulping
- Mechanical pulping
- Recycled paper re-pulping

The scope of pulping is to break the recycled paper or wood down into its component elements so that the fibres can be separated, by removing lignin, a non-fibrous constituent of wood, that is primarily responsible for reducing paper quality and permanence. The fibres are then washed and screened to remove any remaining fibre bundles. The water is finally pressed out and the residue is dried. Pulp can either be used directly or bleached to obtain white paper.

2.1 Raw material preparation

The preliminary operation, before pulping, is the preparation of raw materials (wood).

The primary purpose of raw material preparation is to reduce the size of wood and modify its shape in order to be used in the pulping process. To do so, the wood preparation area of a pulp mill has several functions: to receive and meter the wood supply to the pulping process at the rate demanded by the mill; to prepare the wood so that it meets the mill's feed specifications for species, cleanliness and dimensions; and to collect any material rejected by the previous operations and send it to final disposal. Wood is converted into chips or logs suitable for pulping in a series of steps:

- Debarking is the operation that allows to remove bark from wood. Bark is not used in paper production because of its scarcity in fibres content, its dark colour and its high content of grit; all these characteristics make it anti-economical to be used in pulp production. Debarking is usually performed by stationary or portable industrial machinery that have either an hydraulic motor or a power take-off. The stake or log is placed on the machinery and there are blades or knives that remove the bark while the log is rotating. Other technologies may involve debarking through a high-pressure water jet, even though this operation has a higher environmental cost (it is difficult to dispose of the contaminated waste water produced in this operation).
- Size reduction: debarked logs are cut into smaller pieces suitable to be chipped or directly used for pulp preparation, depending on the type of pulping process.
- Chipping is the operation of cutting wood in very small pieces. Chippers tend to produce chips with a considerable size range, but pulping requires chips of very specific dimensions to ensure constant flow through refiners and uniform cooking in digesters.

- Screening is the operation through which a check is performed to verify that all wood pieces have the correct properties to be sent to the pulping process. Chips are passed over a series of screens whose function is to separate chips on the basis of length or thickness. Oversized chips are re-chipped, while undersized chips are either used as waste fuel or are metered back into the chip flow.

2.2 Chemical pulping

Chemical pulping is responsible for 66% of the pulp produced in Europe. In particular, it is more expensive than mechanical pulping, but the output has higher quality in terms of fibre length, brightness and strength. Chemical pulping foresees the cooking of wood chips with chemicals, in order to remove lignin.

There are two main chemical pulping processes:

- Sulphite process: wood chips are cooked in sulphurous acid combined with limestone to produce calcium bisulphite. Lignin is dissolved by the combination of sulphurous acid and calcium bisulphite. Sulphite pulp is soft and flexible, is moderately strong and is used to supplement mechanical pulps (most typically in newsprint). The main limitation in the use of this process is that it is suitable only for some types of trees and the disposal of waste chemicals is difficult.
- Sulphate process (evolution of the soda process), called also Kraft process, is the most widely used chemical pulping process. It is an evolution of the soda process, developed in the mid-nineteenth century, in which wood chips were dissolved by using a strong base (alkaline solution), such as lye. At the end of XIX century, sodium sulfate was added to the process and a stronger pulp was produced. As a result, the process became known as the sulfate process, even though it was later discovered that the active ingredient is sodium sulphide. The name "Kraft", that is the German and Swedish word for "strength”, is considered more appropriate since the pulp has high strength. This process can be applied on nearly every species of tree, it has internal heat- and chemical-recovery systems and produces high-quality pulp. The obtained pulp is usually dark brown in color and can be used directly, to produce brown wrapping paper, paper bags, envelopes, etc., or it can be bleached if the final product shall be white paper. In the bleaching phase, there is also the addition of fillers, that are used to alter one or more of a paper's properties, depending on the desired end-use characteristics. The properties that can be modified by fillers are, for example, texture, opacity, brightness, basis weight, dimensional stability, ink absorbency and overall printability. According to the desired final product, fillers can be added in different amounts. It has to be considered that increasing the amount of fillers in general improves optical properties but it can decrease a paper's strength and stress endurance. Moreover, fillers reduce paper bulk and stiffness.

2.3 Mechanical pulping

Mechanical pulping uses mechanical energy to weaken and separate fibres from wood via a grinding action. The yield of this process is much higher than in chemical pulping (up to 97%, versus 40-50% of the chemical process), but lignin is not separated and the resulting fibres are shorter, so the quality of produced pulp is lower in terms of strength and permanence; moreover, due to the high levels of lignin, paper develops a tendency to yellow with time. The product has however several desirable printing qualities, such as high ink absorbency, compressibility, opacity and bulk. That's why the pulping produced with mechanical process is used for low-quality printed material, such as newsprint, magazines and catalogues.

There are four types of mechanical pulping:

- Stone groundwood (SGW) pulping foresees the grinding of small logs against artificial bonded stones made of silicon carbide or aluminium oxide grits. The yield of this process is very high, but the produced fibres are very small and shall be mixed with chemically prepared pulp in order to be strong enough to be processed into the paper machine.
- Refiner mechanical pulping (RMP) is the process where grinding is performed by two grooved discs. The yield is as high as in SGW, but the produced fibres are longer and have greater strength, because heat due to friction softens the lignin and allows greater separation of the cellulose fibres, while contributing less fibre damage. Another advantage is that the feedstock can be either logs or wood scraps and sawdust from lumber mills.
- Thermomechanical pulping (TMP) is essentially an RMP process where the chips are steamed before grinding. This process produces a high quality pulp, but its drawbacks are the higher costs in terms of money and energy: the pulp is darker and bleaching is more expensive and a lot of energy is required to produce steam. It is the most common mechanical process used nowadays.
- Chemi-thermomechanical pulping (CTMP) is a TMP process with a chemical pre-treatment of wood chips, in order to have a less destructive separation of fibres from the feedstock, resulting in longer fibres, higher fibre content and far fewer shives. The produced fibres are also more flexible, with improved mechanical properties and brighter ones, with respect to the ones produced with TMP. The main drawback is that it is a high energy intensity process.

2.4 Recycled paper re-pulping

Recycled paper is defined as a paper that is produced, completely or partially, from recovered fibres. The first step is paper collection, performed by the local garbage collection agents. Then, there is selection and sorting, that take places either directly in the paper mill or at special sorting stations.

Once the paper is sorted into different categories, printed paper needs to undergo the de-inking process, that can be either a washing or a flotation. The first is performed in a tank that liberates the paper fibres from the paperweb by agitation with large quantities of water and allows to obtain a slurry. There are centrifugal screens or cyclones to remove undesirable materials, such as staples and slots and screens that allow ink particles through, without letting pulp passing. At the end, fine screening removes adhesive particles.

Flotation, instead, is performed through the addition of special surfactant chemicals in a slurry prepared with the paper waste. Air is blown into the slurry and ink adheres to air bubbles and rises to the surface with them, forming a foam layer that traps the ink. Removal of the foam before bubbles breaking allows to avoid that the ink goes back into the pulp.

The fibre is then sent to storage or directly to the paper making machine and the excess material are either recovered as fuel, or used or landfilled.

2.5 Refining

Refining is the part of the process where the characteristics of the cellulose fibers and the composition of the papermaking furnish that comprise paper are determined, like its resistance to tearing, its porosity, its compressibility, ink holdout and dimensional stability. These properties affect how the fibers bind with each other during the formation of the paper web and what the various optical, structural and chemical properties of the paper will be.

Pulp refining can be performed with two basic methods:

- Batch system: it uses a beater (an oval tank) equipped with rotating metal bars that squeeze the fibers between stationary metal bars, in order to be frayed, shortened lengthwise, swollen in diameter and softened. In this process the surface area of the fibers is increased to facilitate their binding in the other stages of papermaking. The addition of non-fibrous additives can take place at this point. Further refining is performed into a conical refiner (called “Jordan”), where pulp is swirled between a rotating plug and stationary metal bars.
- Continuous disk refiner: it is composed by rotating disks having serrated or otherwise contoured surfaces. One disk rotates clockwise, while the other rotates counterclockwise, or is stationary. This equipment exploits centrifugal force, when the furnish, pumped through the center of one of the disks, is thrown toward the perimeter of the disks and it is squeezed between them. The action of the rotating disks rubs, rolls, cuts, frays and softens the fibers. In continuous refining systems, the type of pulp, the degree of refining and the type and quantity of fillers can be altered easily depending on the type of paper that is to be produced.

2.6 Screening and Cleaning

After pulp production, pulp is processed in wide variety of ways to remove impurities and recycles any residual cooking liquor via the pulp washing process. Some pulp processing steps that remove pulp impurities are screening, defi bering and deknotting. Residual spent cooking liquor from chemical pulping is washed from the pulp using pulp washers, called brown stock washers for Kraft and red stock washers for sulfi te. Efficient washing is critical to maximize return of cooking liquor to chemical recovery and to minimize carryover of cooking liquor (known as washing loss) into the bleach plant, because excess cooking liquor increases consumption of bleaching chemicals. Specifically, the dissolved organic compounds contained in the liquor will bind to bleaching chemicals and thus increase bleach chemical consumption.

2.7 Bleaching

Bleaching is performed on pulp in order to obtain paper that doesn't lose strength with time, doesn't become yellow when exposed to sunlight and doesn't discolour during storage. It consists in the removal of residual lignin by adding chemicals to the pulp (it doesn't matter which process was used to produce pulp, the only constraint on chemicals use is related to the desired finished product). The most common bleaching chemicals are chlorine, chlorine dioxide, hydrogen peroxide, oxygen, caustic and sodium hypochlorite. Chlorinated compounds have been excluded because of the concerns over dioxins, furans and chloroform. Bleaching is performed in bleaching towers, where bleaching chemicals are added to the pulp in stages. Each bleaching stage is defined by its bleaching agent, pH (acidity), temperature and duration. After each stage, the pulp may be washed with caustic to remove spent bleaching chemicals and dissolved lignin before it progresses to the next stage. After the last stage, the pulp is pumped through a series of screens and cleaners to remove any contaminants such as dirt or plastic. It is then concentrated and conveyed to storage. Spent bleaching chemicals are removed between each stage in the washers. Washer effluent is collected in tanks and either re-used in other stages as wash water or sent to wastewater treatment.

3 Paper manufacturing processes

Paper is manufactured in the so-called "Continuous paper making machine". There are three basic types of paper machines: a Fourdrinier machine, a Twin-wire former and a Cylinder machine. Each differs primarily in the forming section or wet end.

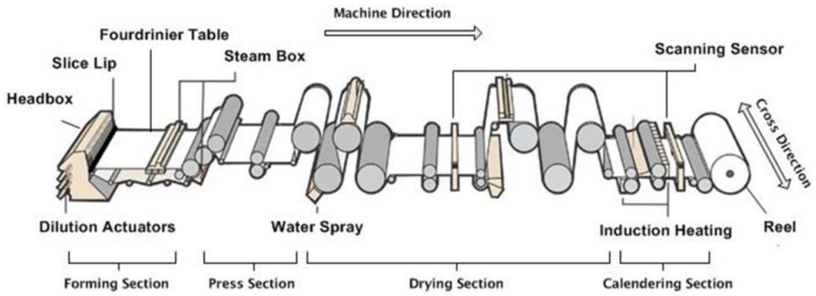

Figure 1: Example of papermaking machine.

3.1 Stock preparation and headbox

At the beginning of the process, the furnish is diluted with water to a fiber-water ratio of 1 to 200. Centrifugal force removes foreign particles such as bits of metal, dirt, plastic and other extraneous material. It is also necessary to keep the fibers from clumping together until it is on the forming wire. Premature clots of fibers (or flocs) result in poor paper formation. The paper machine's headbox keeps the fibers from clotting and regulates the rate at which the fiber suspension is sent to the forming section. The slice is an adjustable rectangular slit that regulates the width, thickness and consistency of the furnish, ensuring that the paper that ultimately forms has properties that are uniform. As the furnish travels through the slice, the individual fibers begin to align in the direction of their flow, forming the grain of the paper.

3.2 Forming section

In a traditional Fourdrinier machine, the water-fiber mixture flows through the slice onto a moving wire mesh belt. As the mixture moves forward, water drains through the mesh and the fibers begin to interlace, forming a mat. More fibers are deposited on top of the previous layer. The belt is supported by suction-cup-shaped foils or turning table rolls that also aid in drainage, usually by suction. Some paper machines increase drainage by oscillating the wire, producing a shake in the direction perpendicular to the direction the wire is moving. The side of the fiber mat that forms on top of the belt is called the wire side of the paper while the reverse is called the felt side of the paper. Since some amount of fine fibers and fillers drain through the wire with the water, the felt side of the paper will have a somewhat different composition and texture than the wire side. Recent innovations have reduced the two-sidedness of paper. As the wire continues with the newly-formed paper web, it passes over vacuum boxes, which suck out water that is beyond the reach of the foils, shake, table rolls, or gravity itself. In many machines, the web now passes under a dandy roll, a hollow, wire-covered roller that improves paper formation. Designs on the dandy roll also add a watermark or the markings typical of laid finish paper. At the end of the forming section of the paper machine, the web passes the couch roll, a perforated cylinder that uses a vacuum to remove even more water.

3.3 Press section

At this point, the web is about 80:85% water and is ready to be sent to the press section which uses pressure and suction to remove and evenly distribute as much moisture as possible and to increase fiber bonding and consequently sheet strength. The press section also affects the paper's final bulk and finish. It consists of a series of two-roll presses, through which the wet paper web passes after leaving the forming section. In each two-roll section, the web travels through the nip of the rolls, which squeezes out moisture, evens out the paper's formation and presses the fibers together, improving their bonding and, ultimately, sheet strength. The press section and the degree of wet pressing affect the ultimate finish and bulk of the paper. Those papers that require high bulk and low finish need less wet pressing than those that require low bulk and high finish. After the press section, the paper—still about 60:70% water—is sent to the drying section.

3.4 Drying section

When it leaves the press section, the web is about 60:70% water by weight. It is further dried in the drying section, where heated cylinders evaporate residual moisture. It is necessary to keep the web under tension to prevent distortions and shrinkage. When the web is dried, its water content will be 2:8%, depending on its end-use requirements. In this section, steam-heated cast iron cylinders evaporate as much residual moisture from the paper web as possible. The paper web snakes through a series of cylinders (as many as thirty in some systems) which alternately expose the web's wire side and felt side to the heated cylinders, so as to ensure consistent drying on both sides of the paper. It is necessary to keep the paper web under tension, so as to prevent distortion and shrinkage. A paper's water content is about 60:70% before entering the drying section and ranges from 2:8% at the end of the drying section, depending on its end-use requirements. Different desired paper characteristics can also vary the drying method used. For example, a Yankee drier can be used for tissue and crepe paper: it consists in a single large, highly-polished, heated metal cylinder used for producing a machine-glazed finish. The wet paper is pressed against the smooth surface of the cylinder and as it dries it takes on a very smooth, glazed surface. In case of tissue and crepe paper, drying is followed by a further process that imparts softness and creping. Another drying method is “air drying”, used to produce high-grade bond, ledger and writing papers by passing the wet paper web, with little or no tension, through an enclosure containing circulating hot air. As the drying paper is allowed to shrink unimpeded, it takes on a rough cockle finish. External sizing, materials added to improve the paper's resistance to fluids and to seal the surface fibers so as to increase sheet strength, is also added at the size press, which is located within the drying section.

3.5 Calendering

The final step for the paper web on the machine is calendering. The machine's calender comprises several steel rollers which impart a dense, smooth surface with consistent thickness. The degree of calendering depends on the desired finish of the paper. Paper is wound into a full-width machine roll and rewinders reduce the roll to the desired width and diameter. The creation of the paper roll is a more complex operation than one would expect. The requirements of any paper roll are printability and runnability and as press speeds increase, new demands are placed on the roll-building technology. Tests are made that generate cross-machine direction profiles of the paper as it comes out of the slice and monitor variations in moisture content and caliper or, in other words, variations in the thickness of the forming web. Any variation beyond certain acceptable tolerances will prevent the web from winding correctly. It is necessary for printers to utilize rolls that unwind with even tension across the roll. If it is wound too tightly, the paper will be stretched beyond its ability to return to its original dimensions. Winding that is slack near the core but tight on the outer portion of the roll will result in a telescoped or starred roll, specific distortions and defects in the paper. New innovations, such as electronic drives and computer controls have contributed greatly to the creation of optimally-wound rolls.

3.6 Finishing section

Finishing refers to the final preparations of the paper, depending on the specific end-use requirements. It can include rewinding, sheeting, trimming, or altering the paper's finish by embossing, supercalendering, or coating.

4 Energy intensity of key processes

According to BREF document, pulp and paper production is an energy-intensive industry. On a global scale, it is the fourth largest industrial consumer of energy, consuming 5.7% of total industrial energy use. Production of pulp and paper requires energy input in the form of heat and power.

According to BREF, the main energy input in pulp and paper manufacturing are shown in the Figure below:

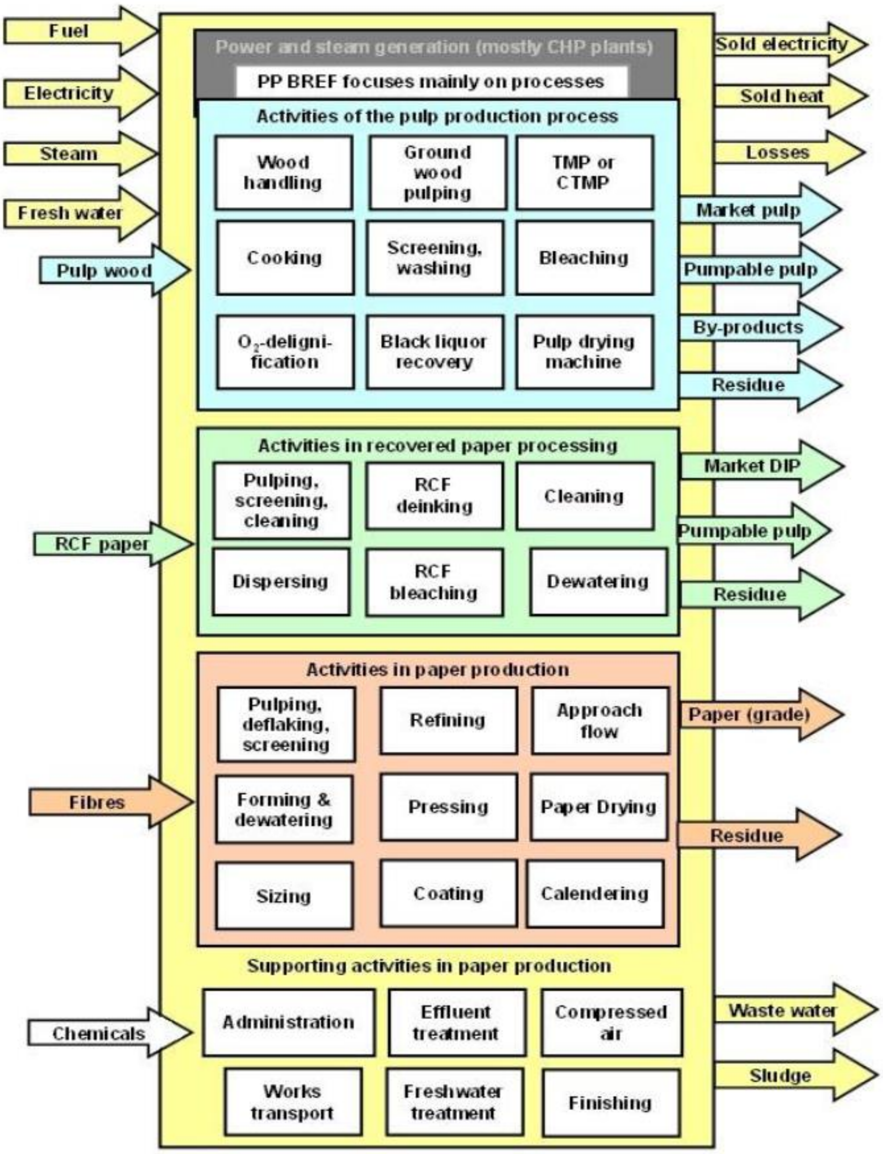

Figure 2: Material and Energy flows in pulp and paper industry.

Heat energy is usually made available in the form of high pressure steam, used to generate electrical power in turbo-generators, with low or medium pressure steam extraction. Steam can be used both in pulping and papermaking. A very large steam consumption is related to the drying section, to evaporate water both from pulp (in pulping plants) or paper (in the continuous papermaking machine).

Electricity is used in several parts of the pulp and paper manufacturing, in general to move motors for different equipment (e.g. frinders, refiners, pulpers, vacuum pumps, compressors).

Moreover, some modern equipment might act in a way that they reduce consumption of heat, but increase the one of electricity, e.g. electric infrared drying or use of modern presses that increase the dryiness of the paper at the press section exit and lower steam consumption in the drying section.

From BREF it is possible to obtain some typical consumption of real plants:

Type of pulp/paper produced	Range of energy consumption		Data source
	Units	from – to	(No of mills)
Non-integrated kraft pulp	Power (kWh/ADt) Heat (kWh/ADt) (7)	700 – 800 3 800 – 5 100	(1) (5 mills)
Integrated uncoated wood-containing paper (includes mechan. pulping (MP) and may refer to GW, TMP or other types of fibres) (5)	Power (kWh/t) (6) Heat (kWh/t) (7)	1 200 – 1 400 1 000 – 1 600	(2) (1 mill); (4) (2 mills)
Integrated coated wood-containing paper (includes mechan. pulping (MP) and may refer to GW, TMP or other types of fibres) (5)	Power (kWh/t) (6) Heat (kWh/t) (7)	1 200 – 2 100 1 300 – 1 800	(2) (2 mills); (3) (8 mills); (4) (3 mills)
Integrated TMP-based printing paper (> 90 % TMP)	Power (kWh/t) Heat (kWh/t)	2 500 – 2 700 330 (8)	Afconsult (1 mill)
Non-integrated coated wood-free paper	Power (kWh/t) (6) Heat (kWh/t) (7)	600 – 1 000 1 200 – 2 100	(2) (5 mills); (4) (2 mills)
RCF without deinking (packaging) paper	Power (kWh/t) (6) Heat (kWh/t) (7)	300 – 700 1 100 – 1 800	(2) (1 mill); (3) (11 mills); (4) (7 mills)
RCF with deinking (graphic) paper	Power (kWh/t) (6) Heat (kWh/t) (7)	900 – 1 400 1 000 – 1 600	(2) (1 mill); (3) (7 mills); (4) (4 mills)
RCF-based cartonboard (with deinking)	Power (kWh/t) (6) Heat (kWh/t) (7)	400 – 700 1 000 – 2 700	(2) (1 mill); (3) (4 mills); (4) (5 mills)
Non-integrated tissue mill (no TAD use)	Power (kWh/t) (6) Heat (kWh/t) (7)	900 – 1 200 1 900 – 2 300	(2) (2 mills); (3) (4 mills)
RCF-based tissue mill (no TAD use)	Power (kWh/t) (6) Heat (kWh/t) (7)	800 – 2 000 1 900 – 2 800	(2) (1 mill): (4) (3 mills)
Wood-free speciality paper	Power (kWh/t) (6) Heat (kWh/t) (7)	600 – 3 000 1 600 – 4 500	(2) (3 mills); (3) (3 mills)

NB:

(1) Swedish EPA, statistical data of Swedish kraft pulp mills, 2005.
(2) PTS, Examination studies: Energy optimisation in European mills (not published), Munich 2004 to 2007.
(3) PTS, Internal data collection of German pulp and paper mills (not published), Munich 2004 to 2006.
(4) Institution for Paper Science and Technology GmbH, Questionnaire-based survey (not published) Darmstadt, 2007.
(5) For integrated wood-containing paper, it should be noted that the combined specific energy consumption of papermaking and mechanical pulping is a directly proportional function of the share and type of mechanical pulp in the furnish. Power consumption for TMP (thermomechanical pulp) is normally higher than for PGW/SGW (pressurised/stone groundwood) and much higher than for RCF (recovered fibre). For more details, the reader is referred to Section 5.2.2.7.
(6) No primary energy is considered, except for gas (lower calorific value) for IR or air dryers or shrink ovens. The power plant is outside the system boundary. To convert the purchased power demand into primary energy used, the energy yield of electricity production of the given country (if known) or at EU level has to be taken into account. e.g. at EU-25 level the total primary energy for generating 1 kWh electricity is 2.62 kWh cumulated energy requirement (source: Global Emission Model for Integrated Systems GEMIS, data taken from EU DG-TREN 2003: European Energy and Transport Trends to 2030 (PRIMES)).
(7) Heat consumption figures exclude heat for electricity production. To convert from [kWh] into [MJ] multiply [kWh] by 3.6; to convert from [MWh] into [GJ] multiply [MWh] by 3.6.
(8) The power consumption for the TMP-refining operation is 2 500 – 2 700 kWh/t of pulp. For more information see Section 5.2.2.7. Of this electricity input, 75 – 80 % is recovered as low-pressure steam, which mainly covers the steam consumption in the paper mill. If everything operates according to good practice, only approx. 1.2 GJ/t (or 330 kWh/t) of additional heat in the form of steam is required.

Figure 3: Typical specific consumption for pulp and paper manufacturing plants.

Several factors might influence energy consumption of a pulp and paper plant. The main ones are:

- Environmental conditions of the production site (e.g. ventilation, heating requirements);

- Age of the plant and equipment: usually older equipment is less energy-efficient than the older ones; however, new technologies take 1-2 years to reach their optimal conditions, so in this timeframe energy consumption might increase;
- Size of the plant (larger plants, in terms of production rates and width of the paper machine, usually have more favourable energy intensity, using scale economy);
- Paper quality and process related conditions, such as speed of rotating equipment (higher speed usually implies higher energy consumption), tight environmental control technologies, pressing and drying technologies required fuel mix (electricity/heat);
- Availability of steam production from biomass boilers or CHP plants instead of fossil fuel boilers.

Ancillary activities (auxiliaries) usually have a low impact in terms of energy consumption in pulp and paper manufacturing sites.