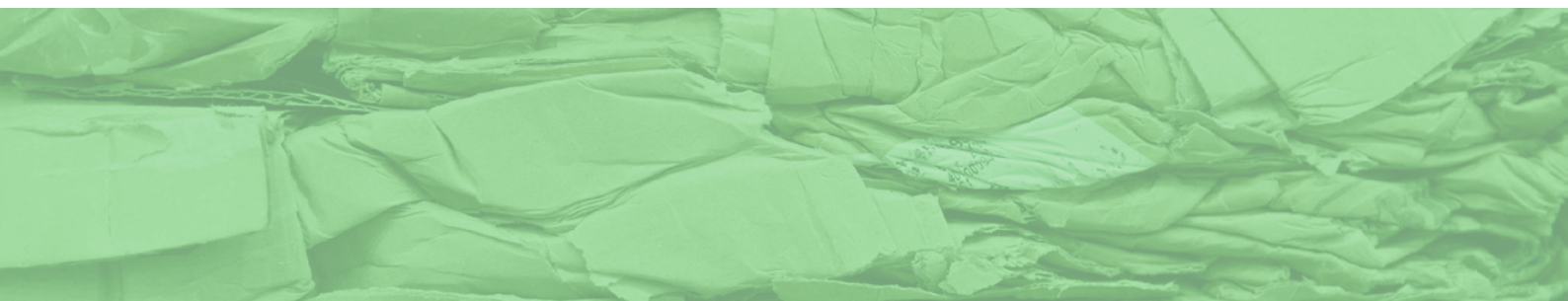


2018

# European Database for Corrugated Board Life Cycle Studies



Cepi ContainerBoard

**FEFCO**  
Corrugated Packaging

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## Foreword

Every three years FEFCO (European Federation of Corrugated Board Manufacturers) and CCB (Cepi ContainerBoard) issue a report and a database of life cycle inventory (LCI) data for corrugated base papers and corrugated products. The goal is to provide high quality and transparent LCI data for use in life cycle studies.

A robust process has been developed in which the data received are processed and checked by both LCA practitioners and industry experts. The results are independent peer reviewed by ifeu – Institute for Energy and Environmental Research Heidelberg GmbH, Germany.

The report explains the production process and the methodology used for the LCI and discusses the input data and results. The Annex of the report contains environmental data of the production of:

- Corrugated base papers from primary fibres: Kraftliner, White Top Kraftliner and Semi Chemical Fluting (based on data supplied by members of CCB)
- Corrugated base papers from recycled papers: Testliner, White Top Testliner and Recycled Fluting (based on data supplied by members of CCB)
- Corrugated board products (based on data supplied by members of FEFCO).

The data in this ninth edition of the report represents the weighted averages of the inputs and outputs from the production sites per tonne of paper and per tonne of corrugated board product for the year 2017.

The database handles the production sites as a black box. Details of the different processes in the production sites are not provided. Emissions originating from production of resources consumed, energy production outside the mill or corrugated plant, transport and waste treatment are excluded from the datasets, but the impacts of these additional unit processes can be added by the user to facilitate full cradle-to-gate or cradle-to-cradle life cycle studies.

The data collected for this study cover a significant proportion of the sector. For Semi Chemical Fluting and Kraftliner, the collected data represent about 85% of the total annual production of corrugated base papers from primary fibres in Europe, whilst the data for the production of Testliner (including White Top Testliner) and Recycled Fluting represent about 58% of the total annual production of corrugated base papers from recovered paper in Europe. Data for corrugated board production covered approximately 54% of the total annual production in Europe. The high levels of data provision mean that the datasets presented in the Annex are highly representative of the practices and subsequent overall environmental performance of the sector.

As experience grows and LCA methodologies evolve, opportunities to improve the quality of the data collected and presented are identified and implemented. During the production of this latest dataset, the following improvements were made:

- Improved data collection for delivery of wood to the mill
- Improved data collection for delivery of recovered paper to the mill
- Improved data collection for transport of corrugated materials from the mill to the box plant

These improvements have allowed more representative transport scenarios to be defined with the available data.

**The report is available for interested parties on the condition that the data may only be used for environmental studies such as Life Cycle Inventory Analysis, Life Cycle Impact Assessment as separate steps or as a whole Life Cycle Assessment.**

The database may only be used for environmental studies regarding product development and improvement. **The database cannot be used for comparisons between the production of primary fibre and recovered fibre-based materials as such or for comparison to other materials.**

FEFCO and CCB are committed to regular updates of the database. The user of the database should therefore check whether it is the latest edition, which will always be available online or through direct contact with either of the Associations involved.

FEFCO and CCB would like to thank all participants from the industry for providing the necessary input from their plants. Collecting, processing and checking the data is a significant undertaking. The high level of ongoing participation of the members of both organisations is highly appreciated.

FEFCO and CCB are also grateful for the positive response and valuable feedback received from users of the previous editions of the database and reports and welcome comments to this edition as well. **Such feedback helps to further improve the quality and value of future updates!**

November 2018

Angelika Christ  
FEFCO

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# 1. Description of production systems

## 1.1. Paper production, a brief description of the process

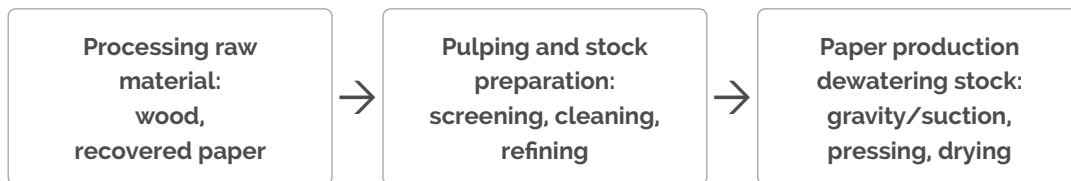


Fig. 1a: Outline of paper production process

### Raw materials processing

#### Wood

The process for the production of Kraftliner and Semi Chemical Fluting starts with wood. Most of the wood is delivered to the mill in the form of pulpwood logs but also a proportion is brought as wood chips from saw mills nearby. The pulpwood logs have to be debarked and chipped before further processing. Therefore the logs have to pass through a barking drum and a chipper.

The chips produced are screened to take away wood dust as well as oversized chips and knots. The oversized chips are reprocessed to get proper chip dimensions and brought back to the chip flow. The chips are stored in a chip pile before processing in the pulp department.

#### Recovered paper

The raw material for Testliner (including White Top Testliner) and Recycled Fluting is delivered as recovered paper in bales and kept on stock by grade.

With a pre-selection method, it is possible to determine the suitability of a certain recovered paper mix for the stock preparation and paper process. The stock preparation is done in accordance with a recipe for each paper grade and grammage. The grades of recovered paper are put on the conveyor to the pulper in the ratio mentioned in the recipe.

### Pulping and stock preparation

#### Pulping and stock preparation of primary fibres

The wood chips are normally cooked to pulp for Kraftliner production by the kraft cooking process. It is a highly alkaline cooking process with caustic soda and sodium sulphide as active cooking chemicals. The cooking takes place in a digester at high pressure and a temperature of 150 -170 °C. The pulp yield is normally around 55% i.e. 1000 kg of dry wood gives 550 kg of pulp.

For Fluting production the wood chips are cooked to pulp by the Semi Chemical cooking process. It is a slightly alkaline cooking process most commonly using sodium sulphite and sodium carbonate as active cooking chemicals. The pulp yield is normally around 80%.

The spent cooking liquor is drained off and washed out from the pulp. It contains the wood substance dissolved during the cooking together with the spent cooking chemicals. The spent liquor is concentrated and burnt for steam production and recovery of cooking chemicals.

The pulp produced is defiberized in refiners, screened and washed before being sent to the paper mill.

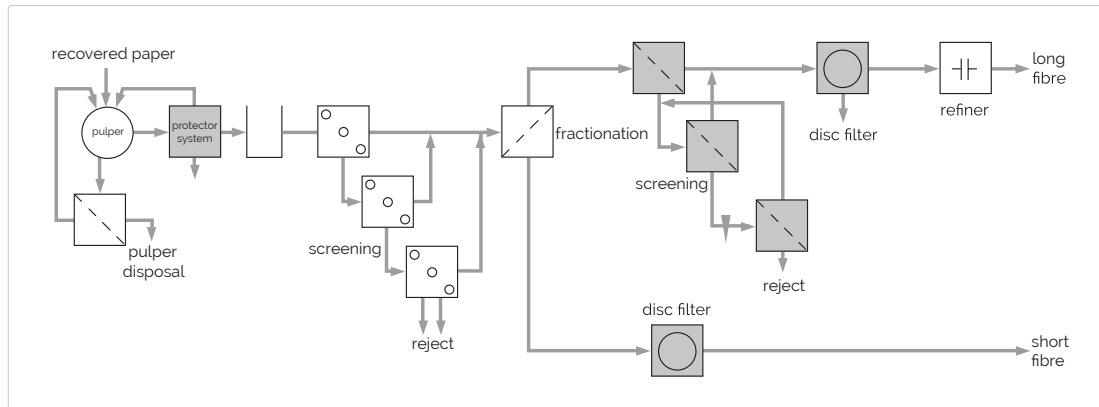


Fig. 1b: Example of stock preparation in recovered paper processing

In the paper mill the pulp is mechanically treated in beaters to improve fibre-to-fibre bonding and the strength of the paper. The pH level of the pulp slurry can be adjusted in some cases to facilitate the paper production. Functional chemicals, fillers and other pulps i.e. recovered paper pulp may also be added to give the final paper the properties required. Finally, the pulp slurry is screened and diluted before being sent to the headbox of the paper machine.

#### Pulping and stock preparation of recovered fibres

In the pulper the blend of dry, baled paper is converted into a pumpable suspension of fibres. This is achieved by submerging the bales in water and agitating the mixture so that the paper is wetted and broken up to form a suspension.

Large contaminants, which do not readily break up, can be removed from the pulper using a "ragger" or "junker", e.g. large pieces of textiles, plastics etc., which are caught on the original wires of the bales.

Remaining undesirable elements in the raw material are eliminated from the pulp by screening and cleaning. After that the pulp may undergo a dispersing treatment. For this treatment the pulp is dewatered by wire or screw presses and concentrated to 25-30% and heated by steam to 80 -100°C. The hot pulp is passed through a type of deflaker (which kneads the pulp) moving through the gap between a stationary and a rotating disk with a lot of teeth.

During the treatment contaminants such as hot melt, wax, ink and coating binders loosen from the fibres and together with small fragments of paper are reduced to fine particles ("dispersed") which therefore are no longer visible. The dispersing treatment also has a positive influence on certain paper characteristics and fibre bonding capability.

#### Pulp for recycled fibre based paper for corrugated packaging does not normally undergo a de-inking process.

The dosage of additives can take place during the stock preparation process, just before/ or in the headbox, on the wire section (e.g. by spraying) or by surface treatment on the size press.

### Paper production

The stock passes through one or two headboxes onto the paper machine. The paper web is formed from the head box onto the wire and dewatered through the wire primarily by the action of gravity and suction/vacuum. Further dewatering by mechanical means takes place in the press section where water is taken out of the sheet by pressing between felts. The final drying takes place in the drying section of the paper machine where the sheet runs against steam heated cylinders to get its final dryness of 91-93%. The collected water is reused for diluting the thick stock coming from the stock preparation.

Semi Chemical Fluting is a paper with just one ply and therefore the paper machine has one headbox and one wire. Kraftliner is normally a two-ply product and therefore requires a paper machine with



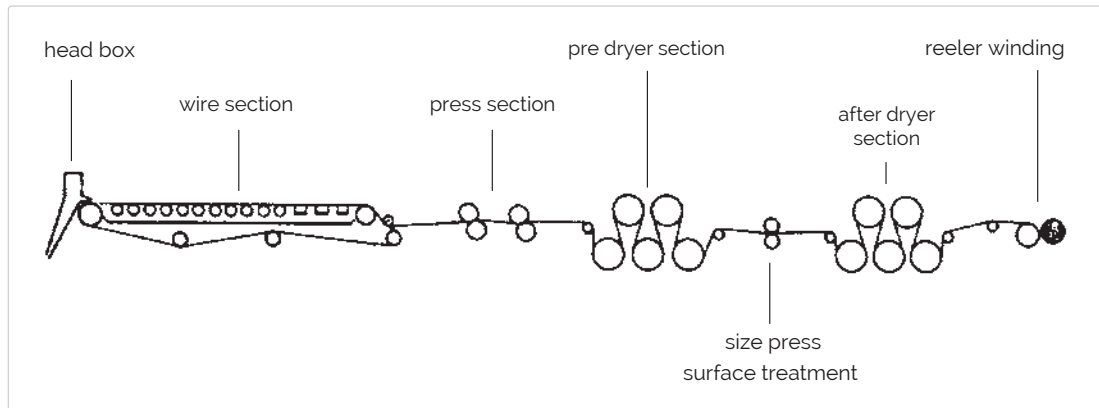


Fig. 1c: Example of paper machine for containerboard grades

two headboxes and usually two wires. The base brown ply contains the internal machine broke pulp in addition to wood fibres from the usually integrated pulp production and could also contain recycled paper pulp. The top ply is normally wood pulp from the integrated pulp production that is more refined and cleaner to give the top surface the right characteristics and printability. For white surface grades bleached fibres are of course used for the top ply.

Testliner mostly consists of two plies of paper. Depending on the type of Testliner the fibre composition of mixes of types of recycled paper can be different in each layer. In general a better grade of mix is used for the upper layer for reasons of appearance and strength. In order to increase its strength Testliner receives a surface treatment in the size press. This involves the application of a starch solution to one or both sides of the sheet. The top ply of Testliner is given an even, mostly brown colour by colouring the mass or by means of the size press treatment. This colouring is never given to White Top Testliners. The addition of special additives (in the mass or by means of the size press) makes it possible to produce Testliners with special properties such as extra water-repellent, low-germ and anti-corrosion grades.

Recycled Fluting can be a one-ply or two-ply product. Usually a size press treatment with a starch solution is applied in-line on the paper machine in order to obtain sufficient strength and stiffness properties.

The most common surface treatment of recycled fibre based corrugated board materials is done by a size press. Essentially a size press comprises two revolving rubber covered rolls, pressed together, through which the paper web passes. In the nip formed by the rolls there is a starch solution. The paper absorbs some of this solution, is pressed between two rolls and goes into the "after dryer" section of the paper machine in order to evaporate from the paper excess water absorbed from the starch solution in the size press.

After the paper machine there is a slitter winder where the big jumbo reel from the paper machine is rewound and cut down to customer reel formats according to customer orders. Finally the reels are weighed, marked, labelled and prepared for shipment to the customer, the corrugated board industry.

## 1.2. Corrugated board production

Corrugated Board is manufactured from a number of specially conditioned layers of recycled and/or virgin papers, called Fluting Medium and Linerboard. Reels of Fluting Medium and Linerboard are fed into a machine called a Corrugator. The Fluting Medium paper is conditioned with heat and steam and fed between large corrugating rolls that give the paper its fluted shape. Starch is applied to the tips of the flutes on one side and the inner liner is glued to the fluting. The corrugated fluting medium with one liner attached to it is called single face web and travels along the machine towards the Double Backer where the single face web meets the outer liner and forms corrugated board. A number of layers of single faced web may be built up to produce double and triple wall corrugated board. The corrugated board is slit into the required widths and cut into sheets which are then stacked or palletised.

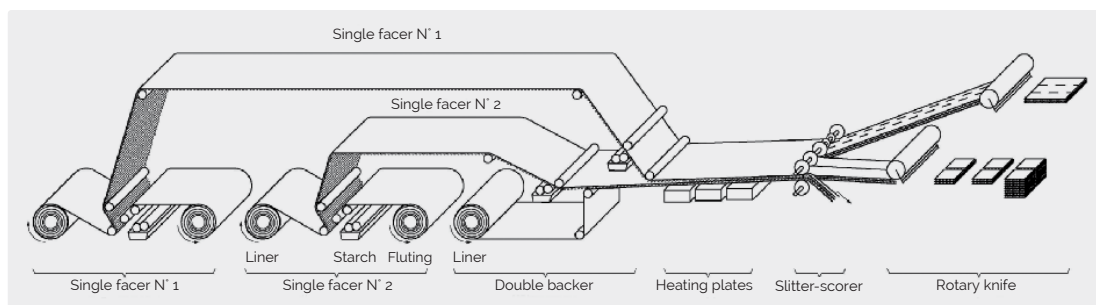
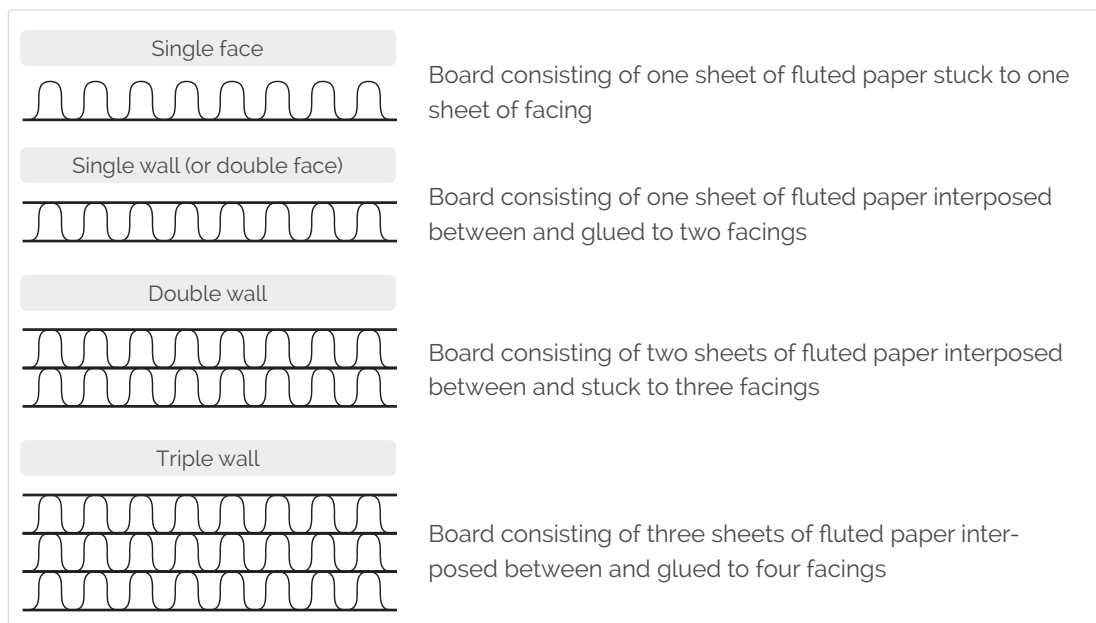


Figure 1d: Corrugated board production



The final stage of the process consists of printing and then slotting, folding and gluing the corrugated board to manufacture a corrugated box.

Most boxes are printed in one or more colours to identify the product they are going to contain, the product manufacturer, the box manufacturer and other information regarding the distributed goods. Different converting operations are carried out according to the customer's specification and according to the type of packaging. The two main categories are the regular slotted box and the die-cut box. The latter concerns packaging that requires a very precise cutting and which can have a complex design.



Regular slotted boxes are usually produced with an in-line flexographic Printer/Slotter/ Folder/Gluer which, in one operation, prints, cuts, folds and glues the board into its final shape.

The die-cut boxes are manufactured on a die-cutter (rotary or flatbed) which cuts and creases the board.

After converting, the corrugated packaging is put on a pallet and delivered to the customer.

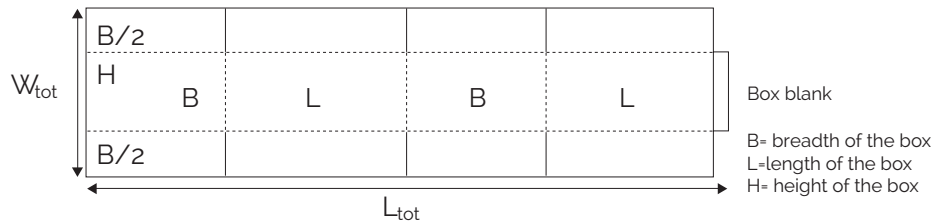


Figure 1e: Box blank

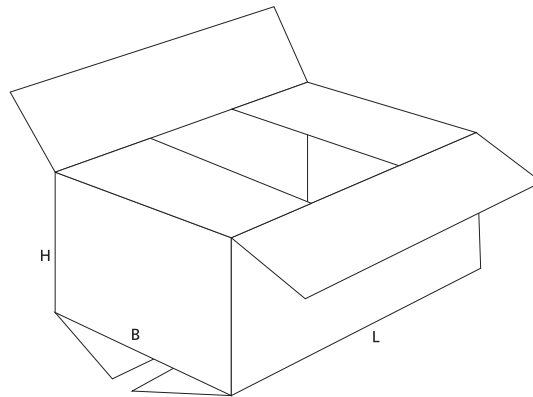


Figure 1f: Converted box

Figure 1e shows an example of a box blank and Figure 1f shows the result when this blank is erected as a converted box

The corrugated board composition of the corrugated box depends on the function that it has to fulfil.

The consumption of liner and fluting can be calculated from the dimensions of the box, grammage of the liners and fluting, what kind of flute i.e. wave type used and weight of the sheet before die cutting. Different wave types lead to different heights of the corrugated layer and to different paper consumption (due to the take-up factor). In Table 1 indicative figures are given for different flute types, as an example.

Table 1: Flute types

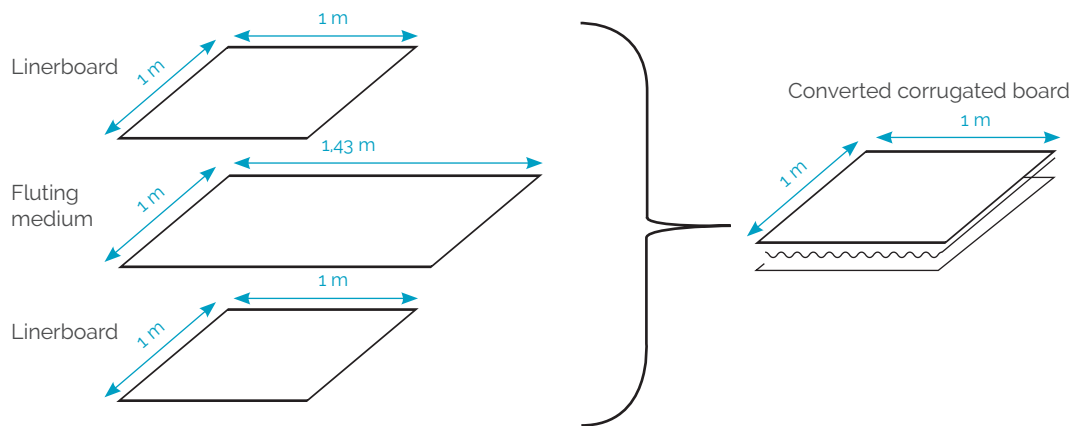
Flute	Flute height* mm	Number of flutes per m length of the corrugated board	Take-up factor	Glue consumption g/m <sup>2</sup> , glue layer
A	4.8	110	1.50-1.55	4.5-5.0
B	2.4	150	1.30-1.35	5.5-6.0
C	3.6	130	1.40-1.45	5.0-5.5
E	1.2	290	1.15-1.25	6.0-6.5
F, G, N	0.5-0.8	400-550	1.15-1.25	9.0-11.0

\*facings excluded

The take-up factor governs the amount of fluting material required to manufacture the corrugated board. It allows for the fact that, when laid out flat before converting, the area of fluting material required to manufacture a defined area of corrugated board is greater than the surface of the converted board itself.

For example, a typical take-up factor for C-flute is 1.43, meaning that 1.43m<sup>2</sup> of fluting (measured flat) is required to manufacture 1m<sup>2</sup> of converted corrugated board, as shown in the example below:

Figure 1g: Illustrating the take-up factor



Example: FEFCO Code 0201  
 Box weight: 650 g  
 Dimensions : 575 x 385 x 225 mm (L x B x H)  
 corrugated board C flute  
 Facings: Kraftliner 175 g/m<sup>2</sup>, Testliner 175 g/m<sup>2</sup>  
 Corrugating  
 Medium: Recycled Fluting 140 g/m<sup>2</sup>

The composition of the corrugated board is then:

	g/m <sup>2</sup>
Kraftliner	175
Recycled Fluting	1.43 x 140 = 200
Testliner	175
Glue	2 x 5 = 10

---

**Grammage** **560**

The corrugated board manufacturer can give the weight of the sheet before die-cutting. For a standard type construction the weight can also be calculated using the International Fibre Board Case Code published by FEFCO. In this code the form of the box blank is shown and by using the box dimensions it is possible to calculate the total length and width of the blank. Adding a 20 mm broad strip to the edges of the blank gives a fair estimate of the sheet area before die-cutting.

In the example  $L_{tot} = 1,95$  m and  $W_{tot} = 0,61$  m. The dimensions of the sheet are:

$$A_{sheet} = (1,95 + 0,04) \times (0,61 + 0,04) = 1,2935 \text{ m}^2$$

and the weight:

$$msheet = 1,2935 \times 560 = 724 \text{ g}$$

Assuming 3% as corrugator trimmings (i.e.  $\eta_{corrugator} = 0,97$ , a common value for modern corrugators), the consumption of liner and fluting can be calculated as follows:

		g/box
Kraftliner	$175 * 1,2935/0,97 =$	233
Recycled Fluting	$200 * 1,2935/0,97 =$	267
Testliner	$175 * 1,2935/0,97 =$	233
Glue	$10 * 1,2935/0,97 =$	13
		<b>746</b>

Total (shavings) =  $746 - 650 = 96$  g/box = 12,9% of the input.

**Please note that this is only an example of a particular box of a certain standard type construction.**

Corrugated board boxes are far from standardised. They show a huge variation in composition, design and appearance. Boxes are usually tailor made to fit the user's needs and requirements which are determined by the product to be packed. The percentage of trimmings/shavings vary according to the design of the packaging.

Since standard boxes do not exist, the database is set up in a flexible way giving the user the possibility to make calculations for any composition needed and using project specific assumptions on transport distance, waste management scenarios etc.

## 2. Methodology questions

### 2.1. Boundaries

This report gives the inputs and outputs from the paper mills and the corrugated board plants separately. Inputs and outputs from the processes mentioned in the grey boxes in figure 2, transport of wood and recovered paper to the paper mill and transport of paper to the corrugated board production sites, are included in the database.

To make a complete LCA study supplementary data are needed (outside the grey boxes in Figure 2) such as environmental impacts of chemicals production, pre-combustion, electricity production for the public grid, transport and waste treatment.

The use of the corrugated box (transportation, protection and identification of the product it contains) is not included in the database. The user has to use the design of the box and details on its transportation containing the product to calculate the full life cycle of the box.

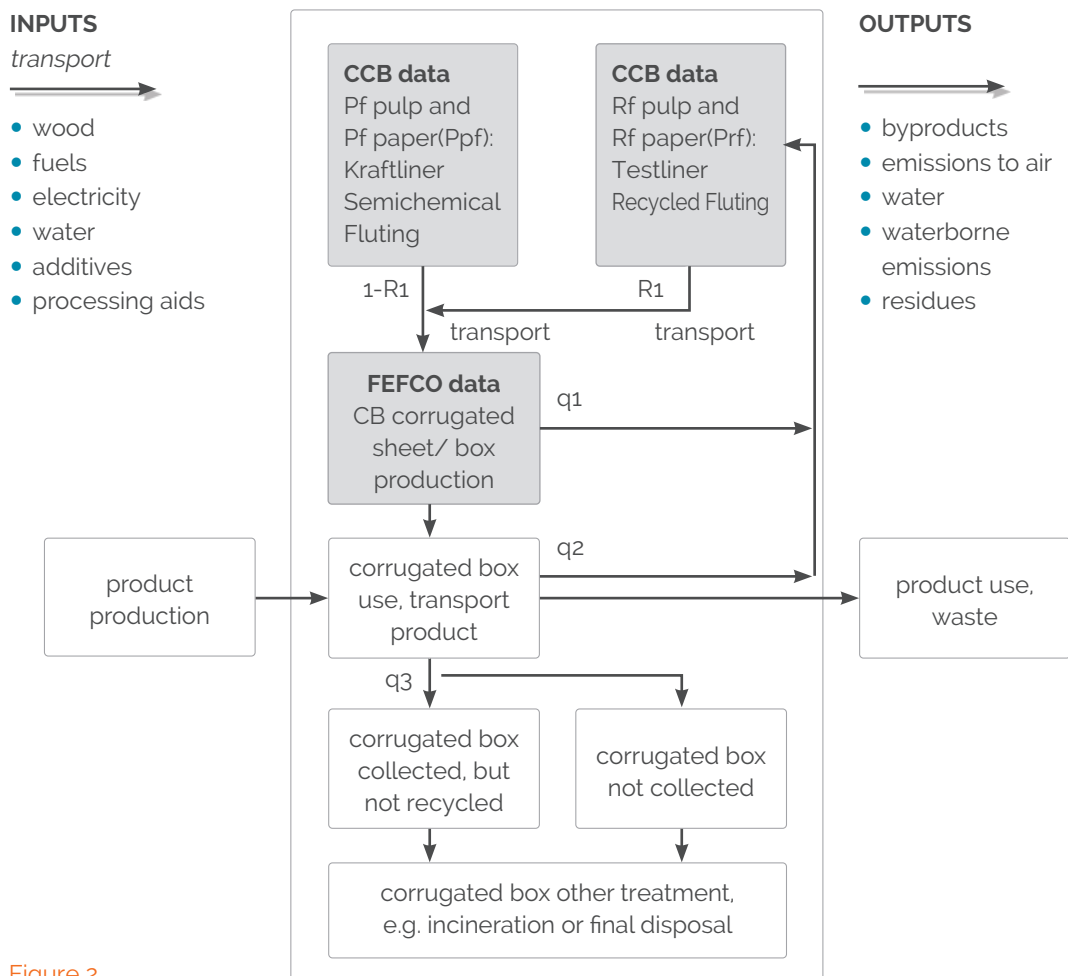


Figure 2

- **Pf paper:** primary fibre based pulp and paper production
- **Rf paper:** recovered fibre based pulp and paper production
- **CB:** corrugated sheet and box production
- **R1** = total of recovered fibre in paper input for corrugated board production/total paper used for corrugated board production
- **r<sub>sh</sub>**: equal to the rate of trimmings/shavings in % of the papers used for corrugated box production
- **R2**= the recovery rate of corrugated board after use
- **q1**= quantity of collected shavings calculated as follows:  $[r_{sh} \times \text{total paper input for corrugated board production}]$
- **q2**= quantity of corrugated board collected after use which is recycled calculated as total corrugated board packaging deliveries)
- **q3**= quantity of corrugated board collected after use which is not recycled (calculated as  $[1- R2] \times \text{total corrugated board packaging deliveries}$ )

## 2.2. Closed-loop approach

When performing environmental studies such as Life Cycle Inventory Analysis for products made from wood fibres, the whole life cycle of the fibres must be evaluated from the fibre production until the fibre is not used anymore, normally after recycling it several times.

Recycling may either be characterised as a closed-loop or an open-loop process. Closed-loop recycling returns the material to the original process and open-loop recycling refers to a product or component going from one system to another for use as raw material in the production of a different product.

To analyse an open-loop system, the inputs and outputs from the linked systems have to be studied. This, however, is not practicable in the case of paper recycling, since the linked systems are extremely complex and very difficult to survey.

To simplify the system, recycling of corrugated board may be looked upon as processing of the primary fibre after use in corrugated board or as raw material processing for the secondary product (or recycled products), also used in corrugated board. At present this is a fairly just simplification seeing that the main raw material for the recovered paper mills is used corrugated board, thus flows in and out of the system of other kinds of paper are ignored.

The problem that remains after this simplification is that choices have to be made to allocate the impacts on the primary fibre based paper and the recovered fibre based paper:

- the impacts of the primary fibre pulp production and the final waste treatments
- the avoided impacts resulting from the recycling.

However, the need for allocation can be avoided (as advised by ISO 14044) by carrying out the calculations as if the recovered material is used in the same life cycle, i.e. by considering the recycling system as a closed-loop. In this case the collected fibres displace the input of primary fibres.

A closed-loop approach requires that the total system is considered during a certain period of time and a specific geographic area. A simplified system for a closed-loop corrugated board packaging system is given in figure 2.

There are different definitions for recycling and recovery (which could mean collection of waste or treatment of waste), depending on the application. This of course leads to the publication of different recycling/recovery rates.

For example, CEN 13440:2003 describes a procedure for calculating the rate of material recycling to demonstrate compliance with the recycling targets given in the Packaging and Packaging Waste Directive 94/62/EC (as amended by Directive 2018/852/EC).

For the system described in figure 2, fibres are recovered (in the sense of collected) from shavings from the production of corrugated board and from collected corrugated board after use, and following that are recycled in a papermaking process to become new paper.

The recycled fibre content (R1) for this report is defined as total recovered fibre recycled from shavings ( $q_1$ ) as well as from used corrugated boxes ( $q_2$ ) divided by the total paper production used for corrugated board production.

- $q_1$  is defined as the weight of production shavings from corrugated board production divided by the weight of the base paper used for the corrugated board production. These production shavings are always recycled. The amount depends on the reference unit. For Europe, the typical amount is about 100 kg/tonne corrugated product, for the converted box it is 147 kg total shavings/tonne.
- $q_2$  is defined as the weight of collected corrugated board after use, effectively recycled divided by the weight of the base paper used for corrugated board production. Recycling is the common practice for collected corrugated board, but it may be that fibres are lost from the loop because not all corrugated packaging is collected. For corrugated board that is not recycled, other recovery

options, such as incineration with energy recovery may take place. According to an estimation based on CEPI statistics for 2014, about 87% (R2) of the corrugated board used in Europe was collected and recycled<sup>1</sup>.

For the purposes of this document, imports and exports of the corrugated board system are ignored, as are used packaging imports and exports. The application of this specific assumption means that the recycling rate of corrugated board (shavings + used packaging) is equal to the recovery rate of these products.

Table 2 shows that the average R1 for Europe in 2017 is about 89%. In this simplified approach this roughly corresponds with the total amount of collected shavings and used packaging as a percentage of the weight of the input of the base papers for the corrugated board production ( $l_{q1} + q_2$ )/total paper production = 86,7%), showing the validity of the closed-loop approach.

#### Note

$r_{sh}$  is not included in the calculation of the recycling rate according to the Directive on Packaging and Packaging Waste 94/62/EC and R2 does not include organic recycling as defined for the same purpose. Therefore, the recycling rate differs from the rate calculated to assess compliance with the recycling targets according to the Directive.

<sup>1</sup> Based in the equation presented in Figure 2, the life cycle of the paper fibres in corrugated packaging is estimated to be fully circular at 85,5%. Within the context of the European recovered paper production environment, recovered fibres will typically be sent for use at the nearest appropriate recycled paper manufacturer. This may not necessarily be a packaging paper line. Some 60% of packaging is recovered at mills producing recycled paper for packaging, some 12% originate from other paper types such as recovered newsprint and the rest, 14,7% is clippings and trimmings from corrugating and conversion manufacturing.



## Definitions and calculations of recovery and recycling

### Definitions of recovery and recycling EN 13193

Definitions set for the Directive on packaging and packaging waste 94/96/EC, as amended by Directive 2018/852/EC.

Recycling: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

Material recovery: any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling.

Packaging waste: any packaging or packaging material covered by the definition of waste laid down in Article 3 of Directive 2008/98/EC, excluding production residues.

### Calculation of recycling rate EN 13440: 2003

$$r_{\eta} = (\delta_1 + \delta_2)/(\alpha + \beta - \gamma)$$

$r_{\eta}$  = recycling rate of used packaging

$\delta_1$  = material for organic recycling

$\delta_2$  = material for material recycling

$\alpha$  = quantity of packaging put on the market for one way use

$\beta$  = quantity of reusable packaging put on the market and used for the first time

$\gamma$  = that part of used packaging which is not available for recycling due to other secondary uses

### CEPI Recycling rate calculation

Recycling rate = utilisation of paper for recycling + net trade of paper for recycling, compared to paper & board consumption.

In 2017, the European Paper recycling rate (for all grades and products) was 72.3% (CEPI key statistics 2017) in Europe (EU-27 countries + Norway and Switzerland), meaning that over 55 million tons of paper-based products have been collected for recycling.

Concerning the Paper & Board Packaging recycling rate in Europe, according to CEPI statistics 2017, it amounts to 82.1%.

## 2.3 Calculation for one tonne of corrugated product

The inputs and outputs per tonne of the average converted corrugated product are reported in Chapter 4. The data include the production of the paper that is needed to produce the corrugated product.

The closed-loop system assumes the ideal case that no recovered fibres are lost from the production shavings and the collected corrugated board after use, and that the fibre quality remains constant due to the reprocessing of the fibres. The primary fibre is thus recycled several times within the system.

The calculation for chapter 4 illustrates the use of the database and the simplified closed-loop approach (no imports/exports, no growth of the loop).

The fibre composition in the containerboard consumption in Europe 2017 (Table 2) is calculated as follows:

- Statistics on the total consumption per grade are provided by CCB
- The primary fibre content is calculated as the total paper consumption per grade minus the calculated recycled fibre amount.

In total this amounts to 3.4 million tonnes of primary fibre and 26.2 million tonnes of recovered fibre, meaning a recycled fibre content of 89% (R1).

Table 2: Base Paper Consumption for Corrugated Board in Europe 2017 (from CCB Statistics)

Million tonnes	Total	Fibre composition	
		Primary	Recycled
Kraftliner	4.6	2.8	1.8
Testliner	10.5	-	10.5
Other recycled liner (Schrenz)	3.1		3.1
Semi Chemical Fluting	0.7	0.6	0.1
Recycled medium (Recycled Fluting)	10.7	-	10.7
<b>Total</b>	<b>29.6</b>	<b>3.4</b>	<b>26.2</b>
		<b>11%</b>	<b>89%</b>

The inputs and outputs for the paper used for the corrugated board production are calculated by multiplying the average relative share of each grade with the data per tonne net saleable product (nsp) for each grade as reported in the Annex. The relative share is calculated from the relative consumption that is found in table 2: 16% Kraftliner, 46% Testliner and other recycled liner, 2% Semi Chemical Fluting and 36% Recycled Fluting. These shares are then added up to average inputs and outputs for the paper production.

The paper production inputs and outputs are then multiplied with the average input of paper (1.147 tonne/tonne corrugated board product) and added up to the inputs and outputs per tonne of corrugated board product as reported in the Annex.

This total includes the production of the paper that is used to produce the corrugated board, including the 14.7% losses that are reported as "paper for recycling".

It has to be kept in mind that the industry averages for inputs of paper, glue and starch are used. As described in chapter 2.1, corrugated board boxes are far from standardised and inputs of paper, glue and starch depend on the box design.

The average transport distances for wood and recovered paper are reported in paragraph 3.7. These data have been used to calculate the transport data in t\*km in chapter 4 and the Annex.

Please note that emissions from transport are not included in the "emissions to air" in chapter 4.

The amount of corrugated board that is not recycled leaves the closed-loop system and is either composted, incinerated with energy recovery, or landfilled. For the above mentioned recovery rate of 89% this means that for each tonne of corrugated board production, 0.89 tonnes is recycled within the closed-loop system and 0.11 tonnes is lost from the system. This figure has to be used in combination with a module for waste treatment/other recovery operations.

\*The grades listed in table 2 are treated according to the definitions in «European corrugated base papers list» first published by CCB in 2008 and most recently updated in 2017. Reference can also be made to the customs nomenclature in Commission Regulation (EC) No 1549/2006.

## 3. Data Description

### 3.1. Participating paper mills and corrugated board plants

The data in this report are based on weighted average data for 2017 of the production per tonne net saleable paper and corrugated board boxes.

The data for the production of the four major paper grades: Semi Chemical Fluting, Kraftliner, Testliner and Recycled Fluting as well as for the production of corrugated board were collected directly from the producers and checked by technical experts.

The data for Semi Chemical Fluting and Kraftliner represent about 85% of the total annual production of corrugated base papers from primary fibres in Europe. The data for Semi Chemical Fluting and Kraftliner also represent about 90% of the total consumption of these grades for corrugated board production in Europe. These paper grades are produced in large mills, located in Austria, Finland, France, Germany, Portugal, Poland, and Sweden. Their total production was 5,438,000 tonnes net saleable paper in 2017. The mills each have an annual production of 94,000-1,128,000 tonnes net saleable paper.

The data for the production of Testliner (including White Top Testliner) and Recycled Fluting were collected from mills, together producing about 58% (14,395,000 tonnes) of the total annual production of corrugated base papers from recovered paper in Europe (EU-27 countries plus Norway and Switzerland). They were provided by paper mills in Austria, Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Poland, Spain, Sweden and the United Kingdom. The mills each have an annual production of 60,000 – 1,300,000 tonnes net saleable paper. The data for the production of White Top Testliner are included in the average of Testliner.

The data on corrugated board production are based on 389 plants (mostly integrated plants with corrugated board and box production on the same site) in Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Spain, Sweden, Switzerland, Turkey and the United Kingdom. Together they produced 12,100,000 tonnes saleable product, which is 54% of the total annual production of corrugated board products in Europe. The production sites have an average annual production of corrugated sheets and boxes of 31,100 tonnes, varying from 5,000 – 500,000 tonnes each.

### 3.2. Questionnaire, definitions, allocation of inputs and outputs to different paper products produced in the same mill

The questionnaires are available through the two Associations as a supplement to this report. A list of definitions is included as well. The questionnaires were slightly modified to improve data collection in some areas, most particularly in relation to transport of raw materials (wood and recovered paper) to the mills and transport of containerboard from the mills to the corrugated board plants. Some improvements were also made with regards to data collected relating to water consumption at the mills and starch consumption at the corrugated plants. The questionnaires for paper mills included a mass balance for recovered paper mills, energy balance, water balance and carbon balance.

The questionnaires treat the paper mills and corrugated board plants as a black box, asking for annual inputs to and outputs from the mill or plant.

Differentiation between the processes within the site, such as power generation, pulping, paper production, wastewater treatment, has not been made.

According to ISO 14044, allocation of the impacts of primary fibre production (the cradle) and waste treatment (the grave) of wood fibre to the phases in between the cradle and the grave of the life cycle

should be avoided, wherever possible. In our case this is done by expanding the product system and considering the expanded system with a closed-loop approach.

In cases where the mill produces other products (e.g. sold energy), the mill reports only the inputs and outputs that were allocated to paper production. No allocation was made to by-products, so the reported inputs and outputs include the production of these by-products.

For those paper mills producing more than one grade of paper and/or market pulp it is necessary to allocate inputs and outputs to the different paper grades or pulp. Mill staff who filled in the questionnaire have done the allocation according to causality.

**Example:**

For a mill producing both Semichemical Fluting and Kraftliner the total input of wood to the mill site has been reported as well as a percentage allocation figure indicating how much of the total wood consumption should be allocated to Semichemical Fluting and how much to Kraftliner.

Details on allocation are described in the following paragraphs of this chapter.

### Checking of the data and the allocation percentages

The collected annual data were processed to determine inputs to and outputs from the paper mills for the production of one tonne net saleable paper for each paper product, using allocation percentages in case more than one product was produced at one mill.

The following calculation was made in most cases:

$$\frac{\text{annual in(out)put} \times \text{allocation \%}}{\text{tonnes Nsp}^2 \text{ produced in 2017}}$$

Some mills have reported waterborne emissions in g/m<sup>3</sup> waste water and for those mills the following calculation was made:

$$\frac{\text{g/m}^3 \text{ waterborne in(out)put} \times \text{allocation \%} \times \text{m}^3 \text{ water}}{\text{tonnes Nsp}^2 \text{ produced in 2017}}$$

To increase the quality of the database the results were checked as described below.

The data per tonne nsp<sup>2</sup> for each paper product were compared by technical experts from the participating mills to investigate if variation of the data could be explained by differences in the applied technology. Data that could not be explained were rechecked to make sure that data from the individual mills were correct.

Mills were also asked to recheck the data in case any of the balances was questionable.

For the corrugated board plants, due to a large dataset of primary data was available it was possible to scrutinise the data statistically for any outlying data points for each inventory item. Where outliers were identified these were either investigated further with the data suppliers or where this was not possible or no satisfactory explanation could be ascertained, such outliers have been excluded from the analysis.

## 3.3. Weighted averages

The database provides the weighted averages of the inputs into and outputs from the sites per tonne net saleable product (paper and corrugated board) for 2017 from the participating paper mills and corrugated board plants. Annual inputs and outputs include periods of shut down.

**It is important to understand that the figures do not represent a certain mill with a certain technology. On the contrary the figures represent a "virtual mill" utilising different technologies.**

The technology which is applied in the participating paper mills and corrugated board plants is not the same.

For example: some mills use a combined heat power generation, some wastewater treatment is external, a large variety of additives is used. In some cases, this leads to a large variation of inputs and outputs between the mills. Furthermore, different inputs and outputs are strongly interrelated, so a mill can be high in one input compared to the others but low in another input, but a mill cannot be low or high for both. Therefore, no range of the data is given to prevent studies from being made using a false combination of highest and lowest data.

Because of confidentiality requirements by the mills it is not possible to split inputs and outputs to data per country. Weighted averages of different technologies is not provided, also for confidentiality reasons a split in applied technologies was not possible.

A few of the requested data could not be supplied by all the participants. In this case the weighted average is based on a limited number of data. These are acknowledged in the dataset with an (\*).

Recycled Fluting and Testliner data was combined to calculate a weighted average for the two grades, since there are few differences between these grades.

Details are given in the following paragraphs of this chapter.

## 3.4. Material inputs and outputs

### 3.4.1. Material inputs

#### Raw Material

The wood input has been reported as bone dry solid wood under bark. The species are specified, although in the datasets they are reported only as softwood or hardwood.

70% of wood used in paper manufacture originates from forests that have been managed according to a certified, third-party verified, sustainable forest management scheme and delivered through a certified chain-of-custody system (PEFC or similar).

A pulp yield (oven dry pulp/oven dry wood) of 54-56% is normal for Kraftliner. A high pulp yield of 80-85% is normal for Semi Chemical Fluting.

The input of recovered paper has been reported as total weight including moisture and other materials (sand, metal objects, plastics, wood etc.). In European countries the water content of recovered paper is generally assumed to be about 10%. The total input of recovered paper is given.

The content of other materials in the recovered paper is about 5%. These materials are eliminated from the pulp as rejects during the pulping. It is estimated that about a third of these rejects are materials that were associated with the previous use of the paper (for example, staples, paper clips, tags, adhesive labels, unrecovered fibres, etc). The remaining two thirds is material that is not in any way associated with the previous use of the paper (for example, foreign items such as textiles, plastic packaging, glass, sand and grit, etc).

The main raw material inputs for corrugated board production are different grades of paper. The liners are used for the surface layers of the corrugated board, fluting is used for the corrugated layers.

As pointed out in chapter 1.2 there are endless possibilities for the composition of corrugated board. The amount of the different grades of paper and glue used as input for the corrugated board production varies accordingly. These inputs should be considered when the LCA of a certain box is studied. An example is given in chapter 1.2.

This should be kept in mind when considering the averages for paper consumption and the additives for corrugated board production in chapter 4.



### Chemicals and other non-fibre inputs

Data were collected for chemicals and other non-fibre inputs which may be used either within the process or as additives.

Inputs of chemicals or additives at less than 5 kg/tonne net saleable product per mill are calculated as zero in the calculation of averages of each of the five production processes reported in the Annexes. Chemicals are given as dry weight.

Some of the inputs have been reported grouped together according to their function in the mill. The functional additives, mainly starch, influence the properties of the paper, whilst process additives are used to guarantee that the process of paper production runs smoothly or to increase the production.

Water treatment additives include additives used for all water treatment on the site, including the treatment of water for the power station, paper production and waste water treatment if this is done internally. The different mills use a large variety of process and water treatment chemicals. Those that are commonly used and are above the cut-off criterion per mill are reported in the database.

A very limited quantity of other additives, e.g. synthetic polymers (polyethylenamine, polyacrylamide, polyvinylamine) are being used.

The main input for corrugated packaging is starch glue, containing starch and small amounts (less than 0.5 kg/tonne nsp) of caustic soda, borax, and wet strength agent. Only a few plants laminate the board and/or add a protective coating. All reporting plants that print the board use the flexo printing technique. For box making cold glue and small amounts (< 0.1 kg/tonne nsp) of hot melt, tape (paper or plastic), plastic tear strip and stitch wire are used.

### Packaging

Data on cores and other packaging materials associated with paper reels was not collected and updated for 2017. Looking at previous data collections, the values showed little change over the years and other LCA studies show that the impacts of these packaging components are relatively small.

For corrugated board products, data on packaging materials used around the product have been reported. Packaging for corrugated board products amounts to relatively small inputs of tape, wrappings of paper or plastic film, steel bands and pallets used as packaging of the saleable product. Pallets are also used in the logistic operations of the corrugated board industry. However, data on usage of pallets has not been collected. Previous iterations of the study have shown that the reported data on the use of pallets are confusing because of the complexity of the matter. Pallets can be returnable or one-way, only used internally in the plants and produced of wood, plastic or paper/wood combinations. Previously some plants have reported their use in number of pallets while others have reported in kilogram pallet per tonne net saleable product, making it difficult to produce a meaningful figure.

### Allocation to paper grades when a mill produces more than one paper grade

The basic data for raw material and chemical inputs are mainly based on recipes used for the production. When allocation was necessary, this was done according to mass production of the different papers.

## 3.4.2. Material outputs

The main output from the paper mills is of course paper. This includes about 2 kg of cores and plugs per tonne paper, which are considered and weighed as part of the net saleable product. The corrugated board plants produce corrugated board and boxes.

The average moisture content of the saleable product is 9% for Semichemical Fluting and 8% for Kraftliner, 7,5% for Testliner and Wellenstoff, 7-8% for corrugated board.

The main saleable by-products from the production of Kraftliner are tall oil and turpentine. These are included in the report.

### Residues

All residues are reported as wet weight, separated according to their basic nature. Residues are reported irrespectively if they are deposited internally within the site or externally, in the latter case normally at a deposition cost.

The waste treatment was not reported by all mills.

From the residues of the recycled paper mills, which are mainly rejects from the pulp preparation, it is estimated that about a third is due to rejected materials that were associated with the previous use of the paper (for example, staples, paper clips, tags, adhesive labels, unrecovered fibres, etc). The remaining two thirds is material that is not in anyway associated with the previous use of the paper (for example, foreign items such as textiles, plastic packaging, glass, sand and grit, etc).

Primary sludge from wastewater treatment in mills producing Testliner and Recycled Fluting are mostly recycled in the process and do not leave the site.

Ashes, green liquor sludge and lime mud are commonly reported residues from the production of primary fibre-based paper. They are usually landfilled (LO), but lime mud is also used as fertilizer.

For corrugated board the main waste stream is paper for recycling, which is recycled and thus should not be called waste but recyclable material.

### Allocation of residues to paper grades when a mill produces more than one paper grade

Data for material outputs are based on measurements. These have to be done because the mills have to pay for landfill and incineration or get paid for residues that are reused or recycled, like lubricants, according to the weight. When allocation was necessary, this was done according to mass of the different papers.

There is no technical reason for differences in residues between Testliner and Recycled Fluting. However, the weighted averages for each paper grade do show differences because different mills are included in the samples. To prevent misunderstanding, the same amounts of residues for both paper grades are reported as their weighted average.

## 3.5. Energy input and output

Fuel inputs to the sites have been reported in GJ. The lower calorific heat values have been used to calculate GJ from m<sup>3</sup> or tonnes of fuel. Fossil fuel and biomass fuel have been reported separately.

The energy figures for the sites include both energy for process and energy for infrastructure. No attempts have been made to differentiate between these two types of energy usage because process energy dominates (98% or more).

Input of electricity into the sites is also reported. The electricity produced at the site itself is not reported. Some mills sell energy externally in the form of electricity, steam or warm water.

The production sites are treated as a black box in the database, giving data on inputs and outputs only. Because no information is given about what happens within the box it is not possible to calculate an energy balance with the data in the database.

Within this black box, energy is recovered through the burning of black liquor and bark from the wood coming in at production sites for primary fibre-based paper production. Most of the energy used in the process for Kraftliner production comes from internal burning of the black liquor. This inherent energy is not reported as part of the fuel input. The total energy input for the process for Kraftliner production including the black liquor burning is around 13 GJ/tonne. The total energy input for the process of Semi Chemical Fluting production is around 10 GJ/tonne. Energy from internal incineration of rejects at the site is also not reported as part of the energy input.

Combined heat power generation is applied at most of the production sites for recycled fibre based paper, but not always in the same way. The combined heat power generation can cover all or part of

the steam consumption (figure 3). When it covers only part of the steam consumption, then additional boilers also produce steam.

The process always uses more heat (steam) than electricity. Therefore, when the installation is designed to cover the whole steam consumption more electricity is generated than what is needed for the process. The excess of electricity is sold to the public grid.

There are two possible ways of treating this excess electricity in an LCA.

- a. The production of electricity is an integral part of the paper production: it would not be produced if the paper were not produced. Paper is thus considered as the only "product" of the process. In an LCA this would mean that electricity generation for the public grid is "saved" when an excess of electricity produced at a paper mill is sold to the public grid. Thus environmental inputs and outputs are saved since combined heat power installation produces electricity with a higher efficiency than the public grid.
- b. Another possibility is to consider the paper and excess electricity as co-products. Paper and electricity are then both "products" from the process. In an LCA this would require allocation of inputs and outputs to both products.

The reported weighted averages of the fuel consumption and emission to air associated with the paper production are calculated according to method b, as this has become common practice at the mills. This means that the fuel consumption and emissions to air do not include the production of the sold electricity and the amount of the sold electricity is not reported. This was calculated as follows: the fuel consumption and emissions to air associated with the total heat production and the net electricity used on site were allocated to the paper production.

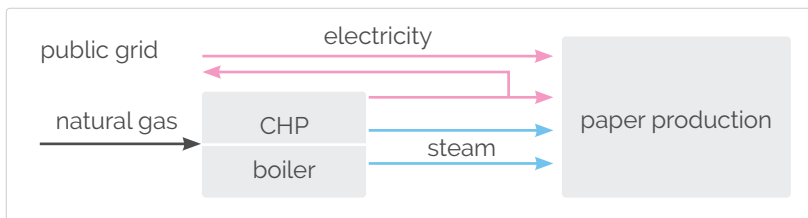


Figure 3: CHP, combined heat power generation

Diesel or gasoil/LPG used for internal transports are reported.

Most of the energy consumed by the mills producing Kraftliner are by-products from the process and thus originates from the trees i.e. have biomass origin.

### Allocation of energy to paper grades when a mill produces more than one paper grade

The energy is measured, because it is paid for. Allocation for fuels and electricity input is calculated according to energy (heat and electricity) required for the production of the different paper grades. Allocation of the other fuels, such as diesel oil used for internal transportation, was calculated according to mass production of each paper grade.

There is no technical reason for differences in energy consumption between Testliner and Recycled Fluting. However, the weighted averages for each paper grade do show differences because different mills are included in the samples. To prevent misunderstanding, the same amounts for energy consumption and emissions to air for both paper grades are reported as their weighted average.

### 3.6. Water inputs and outputs

When paper mills use water, they do not consume this water during the production process. After (re)use it is returned to the rivers, lakes or seas as cooling water and purified effluent water. A limited amount of water is evaporated (about 1-1.5 m<sup>3</sup>/tonne nsp) in the drying section of the paper production.

The water debate focuses on the impact of water consumption. This is best reflected in the local water availability rather than in the amount of water taken into the mills. Therefore, the appropriate indicator is the net difference of water taken in and water returned to the rivers or lakes (water consumed, not taken in).

### 3.7. Transport

The transport distances of wood raw materials from the harvesting sites in the forests to the mills have been reported separately for trucks, rail and ships. The trucks and rail wagons are normally loaded to full capacity but go back empty. The trucks carry 40-44 tonnes of wood. This information has been collected on a species-species basis for each mill, considering the wet weight of the wood. Data has also been collected for the delivery of saw mill residues and similar sources of fibre. Distances and tonnages of wood delivered have then been used to calculate the total t.km for delivery of wood by each mode of transport (truck, rail and boat). This is then used to calculate the t.km/t of production for each grade (Kraftliner, Semi Chemical Fluting and Recycled Fluting and Testliner) at each mill, calculated on a mill-by-mill, input-by-input basis. A weighted average t.km is then calculated based on the relative production share of each mill.

A similar approach is applied for calculating the transport requirements for recovered paper. Transport distances from point of origin of the recovered paper bales to the mills have been reported on a recovered paper grade-by-grade basis for each mill. Distances and tonnages of recovered paper delivered have then been used to calculate the total t.km for delivery of recovered paper by each mode of transport (truck, rail and boat). This is then used to calculate the t.km/t of production for each grade (Kraftliner, Semi Chemical Fluting and Recycled Fluting and Testliner) at each mill, calculated on a mill-by-mill, input-by-input basis. A weighted average t.km is then based on the relative production share of each mill. Generally, the lorries are loaded to full capacity. On the return trip it is estimated that 40% of the trucks return empty.

Assuming this is transported by a truck with a loading capacity of 40 tonnes this means that this figure has to be used in combination with data on inputs and outputs for transport by a 40t truck.

Transport of the residues was not included in the questionnaire as this was seen to be part of the residue treatment. During the discussions with the technical experts it became clear that the transport of rejects is mainly to nearby landfill, 3-30 km.

Data was also collected from the papermills on average delivery distances and modes of transports to their customers. This data was provided on a product-by-product basis and was used to calculate a weighted average t.km for delivery of paper to the corrugated board plants.

However, any one corrugating plant will of course source the substrates they use from many different suppliers. Therefore, the values presented in the inventory are only indicative and in practice users of the data may wish to consider delivery of materials on a case-by-case.

Internal transport is included in the energy input (paragraph 3.5).

### 3.8. Emissions to air

Emissions from fuel combustion (transport, electricity generation for the public grid) outside the mill are not included in the data. As described in 3.5, in case the site sold electricity, the emissions associated with the sold electricity are not included.

Emissions to air from the sites have been reported. For dust, TRS (H<sub>2</sub>S), NO<sub>x</sub> and SO<sub>x</sub> the figures from the paper mills are mostly based on measurements. For CO<sub>2</sub> the figures reported are based on calculations and reported separately for fossil and biomass origin.

Corrugated board plants have no measured air emission data to report. Therefore, the air emission figures for corrugated board production reported in chapter 4 and in the Annex are calculated from reported figures for consumption of different fuels in the corrugated board plants. The emission factors in table 4 were used for the calculations.

	unit	natural gas	oil heavy	oil light/diesel	coal
CO <sub>2</sub> (fossil) <sup>1</sup>	kg/GJ	56	78	74	95
CO*	g/GJ	2.1	7	4	100
Particulates, < 2.5 µm <sup>2</sup>	g/GJ	0.2	35	0.1	20
Particulates, > 2.5 µm, and < 10µm <sup>2</sup>	g/GJ		5		20
Particulates, > 10 µm <sup>2</sup>	g/GJ		10		10
NO <sub>x</sub> (as NO <sub>2</sub> ) <sup>2</sup>	g/GJ	18	100	50	200
SO <sub>x</sub> (as SO <sub>2</sub> ) <sup>2</sup>	g/GJ	0.55	400	47	500
ecoinvent dataset name and ID-number		natural gas, burned in industrial furnace >100kW, RER, [MJ] (#1363)	heavy fuel oil, burned in industrial furnace 1MW, non-modulating, RER, [MJ] (#158g)	light fuel oil, burned in industrial furnace 1MW, non-modulating, RER, [MJ] (#1601)	Hard coal, burned in industrial furnace 1-10MW, RER [MJ] (#848)

<sup>1</sup> Source Intergovernmental Panel on Climate Change (extracted from Emission Factors Database, IPCC Guidelines version 2006)

<sup>2</sup> ecoinvent Centre, ecoinvent data v2.2 Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent data v2.0, 2007, Swiss Centre for Life Cycle Inventories, PSI, Duebendorf, CH, [www.ecoinvent.org](http://www.ecoinvent.org), 2012

Table 3: Default factors for calculating emissions to air

Emissions to air in the flue gas from the CHP the power station are given for the mills producing Testliner and Recycled Fluting that use combined heat power generation. Emissions from the incineration of rejects with energy recovery at the mill are included.

Emissions in the steam from the drying section of the paper machines are not included.

When mills have anaerobic wastewater treatment on the site, biogas originating from this process is used as a fuel by the mill. The emissions to air originating from the use of biogas as fuel are included.

The volume of the total flue gas stream was not asked in the questionnaire not the means of flue gas treatment.

Very few mills were able to report any figures for emissions such as metals etc. Where data was reported the same substances were not always covered and where common emissions were reported these showed a large variation per mill, primarily due to differences in measuring/monitoring and/or calculation regimes. Therefore, this information has not been included in the datasets. For conducting their own LCI or LCA studies, users of the dataset are advised that they should include such emissions. These can be estimated through the application of standard emissions data for the combustion of different fossil fuels, together with the amount of fossil fuels used in the processes (as indicated in chapter 4 and the Annex). This will allow an estimation to be made of the order of magnitude of these emissions.

### **Allocation of emissions to paper grades when a mill produces more than one paper grade**

Emissions to air are calculated from measurements, applied technology, permit values or from the input of fuels. Necessary allocations were done in the same way as for energy input.

## **3.9. Emissions to water**

Water that is taken in must be treated before it is used in the process, and it is again treated after the process before it is released as effluent to a recipient. The substances in the effluent after wastewater treatment are reported.

All mills have some sort of effluent water treatment, either mechanical treatment by sedimentation or in addition biological anaerobic and aerobic or chemical treatment of the effluent.

A few mills send their effluent water to an external communal treatment plant.

The volume of effluent water is reported separately for treated process water and thermally polluted effluent (e.g. cooling water). All mills have reported the figures for outgoing effluent water to the recipient i.e. effluent water after final treatment.

The amount of substances (COD, BOD, suspended solids) per m<sup>3</sup> of effluent from the different mills show very little variation when the efficiency of the waste water treatment station is the same. The amount of substances per tonne paper production may however vary according to the amount of effluent, depending on specific circumstances in the paper production process in the different mills.

In the questionnaire for data collection, a number of other emissions were asked for such as oils, nitrates, acids, AOX, chlorate, chlorides, borates, phenol, Hg, Pb etc. Few mills were able to report figures, probably because there are no or few measurements. Only COD, BOD<sub>5</sub>, suspended solids, total nitrogen and total phosphorus are based on data from most mills in addition to the total volume of effluent waters.

Due to the water treatment it is possible that the content of certain substances per m<sup>3</sup> is higher if the water is taken from a river than in the effluent released into the river. In an LCA this would mean that the production of paper could be credited for the reduction in substances. This is illustrated in figure 4.



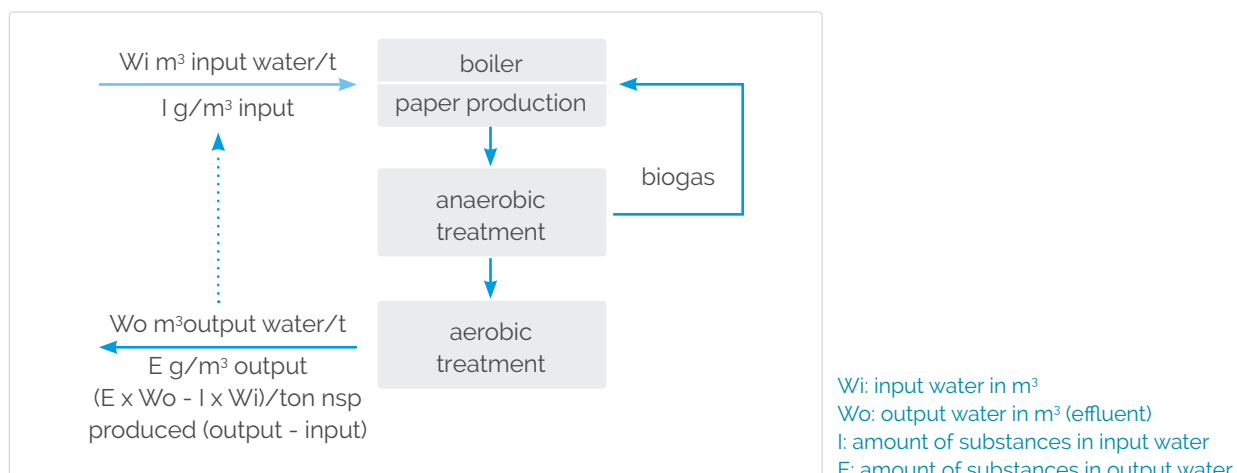


Fig. 4: Credit for reduction of substances in the effluent water

Since only a few mills analyse their incoming water the available data cannot be considered as representative. Therefore, only data for the emissions to the recipient are given, without taking into account the substances in the incoming water.

Most of the corrugated board plants have internal waste water treatment that can be treated externally afterwards.

In case the waste water is not further treated externally and released to the environment, the emission level of substances is so low that reporting them is not required by authorities. The reported data are therefore based on a small sample.

Besides the substances reported in chapter 4 and the Annex, very few plants have also given data on some of the following emissions: metals (Cadmium, Chromium, Lead, Nickel, Iron, Boron, Aluminium), AOX, Chlorine and Phosphorus. The amounts are below 0.001 kg/tonne nsp.

### Allocation of emissions to paper grades when a mill produces more than one paper grade

As far as waterborne emissions per m<sup>3</sup> are measured for a mill, these data are well documented.

The figures reported are usually based on continuous measurements according to control programmes set by official authorities. Given emissions to water are measured according to standard methodology.

Where necessary, allocation between paper grades is done according to mass of produced paper grade. There is no technical reason for differences in water consumption, effluent and emissions to water between Testliner and Recycled Fluting. However, the weighted averages for each paper grade do show differences because different mills are included in the samples. To prevent misunderstanding, the same amounts for water use, effluent and emissions to water for both paper grades are reported as their weighted average.

The water used for the production of White Top Testliner is relatively higher than for Testliner and Recycled Fluting. No separate data are reported as the effluent from its production is mixed with that from the production of other grades produced on site.

Data on emissions to water from the corrugated plants were also collected. However, the corrugated plants are not subject to Industrial Emissions legislation, and therefore the quantity and quality of available data is inconsistent. This is further complicated by the fact that the corrugated plants do not all have their own effluent treatment facilities or treat only certain aspects of the waste water associated with specific processes (for example, ink recovery). Many plants discharge a proportion of their wastewater under specific agreement to public effluent treatment facilities and therefore do not have access to data on the releases to the environment (after final treatment). It did not prove

possible to make a reliable analysis with the data collected during the latest survey. For this reason, data representative of emissions after a public waste water treatment plant were considered for the waste emissions from the corrugated plant.

## 4. Data

**The database may only be used for environmental studies regarding product development and improvement. The database may not be used for comparisons between the production of primary fibre and recovered fibre-based materials as such or for comparison to other materials.**

The production of corrugated board is normally expressed in m<sup>2</sup>.

For LCA it is preferable to have it expressed in weight.

The table shows the calculated inputs and outputs for the production of 1 tonne of corrugated board in Europe with an average paper grade composition. The explanation of the calculation is reported in chapter 2.3.

For the average corrugated board product, the paper input is 1.147 tonnes/tonne corrugated board, with an output of 0.147 tonnes paper for recycling.

Please note that corrugated board boxes are far from standardised. They show a huge variation in composition, design and appearance. Boxes are tailor-made to fit the user's needs and requirements determined by the product to be packed. The amount of paper and glue, percentage of trimmings/shavings vary according to the design of the packaging.

On average 1.147 tonne of paper is used to produce one tonne of corrugated board. The original five datasets for the four main paper grades and corrugated board production from which the data are derived, are reported in the Annex. The data for the corrugated box is calculated by multiplying the average paper grade composition by 1.147 and adding the corrugated board data reported in the Annex.

Averages are only given for parameters that were available from all five data sets.

The average for the main additives by weight (input of more than 1 kg) are given, in total covering 90% by weight of the total input of additives.

PRODUCT		2018
	<b>tonne net saleable product</b>	<b>1</b>
<b>SOLD BYPRODUCTS</b>		
Tall oil	kg/t	3,46
Turpentine	kg/t	0,25
RAW MATERIAL		
<b>Wood consumption</b>	<i>as bone dry weight (= 45% of transported total wet weight)</i>	
Softwood logs	t/t	0,16
Hardwood logs	t/t	0,04
Saw mill residues, softwood	t/t	0,02
Saw mill residues, hardwood	t/t	0,00
<i>Total wood</i>	<i>t/t</i>	<i>0,22</i>
<b>Recovered Paper</b>	<i>as wet weight</i>	
Category		
Mixed Grades	t/t	0,58
Corrugated and Kraft, pre-consumer	t/t	0,11
Corrugated and Kraft, post-consumer	t/t	0,36
Newspaper and Magazines	t/t	0,00
Other grades	t/t	0,04
<b>Purchased pulp consumption</b>	<i>as bone dry weight</i>	
Bleached pulp	t/t	0,0032
Unbleached pulp	t/t	0,0003
<b>Paper consumption for corrugated board production</b>		
Total	t/t	1,15
Cores	kg/t	2,53
Core plugs	kg/t	0,06
TRANSPORT OF RAW MATERIALS		
<b>Wood</b>		
Wood with truck	t*km	88,00
Wood with rail	t*km	71,16
Wood with boat	t*km	226,65
<b>Recovered paper</b>		
Recovered paper with truck	t*km	344,38
Recovered paper with rail	t*km	21,43
Recovered paper with boat	t*km	32,21
<b>Paper to corrugated board plants</b>		
Paper with truck	t*km	523,03
Paper with rail	t*km	373,92
Paper with boat	t*km	1987,75

ENERGY INPUTS		
<b>Steam</b>	GJ/t	0,48
<b>Bought Electricity</b>	GJ/t	1,24
<b>Fossil fuels</b>		
Natural gas	GJ/t	4,60
Heavy fuel oil	GJ/t	0,05
Light fuel oil	GJ/t	0,04
Diesel oil	GJ/t	0,01
LPG	GJ/t	0,05
Coal	GJ/t	0,54
Lignite	GJ/t	0,08
Peat	GJ/t	0,00
<i>Total fossil fuel</i>	<i>GJ/t</i>	<i>5,43</i>
<b>Renewable fuels</b>		
Biofuel (bark, scrap wood, tall oil)	GJ/t	0,76
<i>Total renewable fuel</i>	<i>GJ/t</i>	<i>0,76</i>
<b>Refuse Derived Fuel</b>		
	GJ/t	0,17
<i>Total fuel</i>	<i>GJ/t</i>	<i>6,18</i>
WATER		
<i>Input total</i>	<i>m<sup>3</sup>/t</i>	<i>13,55</i>
Ground water	m <sup>3</sup> /t	
Ground water (non-renewable)		1,14
Ground water (renewable)	m <sup>3</sup> /t	1,87
Surface water	m <sup>3</sup> /t	9,92
Municipal water supply	m <sup>3</sup> /t	0,68
Rain water		0,03
Other water recieved		0,07
<i>Water in-out</i>	<i>m<sup>3</sup>/t</i>	<i>1,07</i>

**PROCESS CHEMICALS AND ADDITIVES, DRY MASS**

Alum (Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> )	kg/t	0,65
Biocides	kg/t	0,16
Borax	kg/t	0,14
CaCO <sub>3</sub>	kg/t	1,23
CaO	kg/t	0,72
Coagulant	kg/t	0,00
Colorants	kg/t	0,75
CO <sub>2</sub>	kg/t	0,55
Defoamer	kg/t	0,29
Fillers	kg/t	3,12
Glue, cold + hot melts	kg/t	0,65
H <sub>2</sub> O <sub>2</sub> , peroxide	kg/t	0,47
H <sub>2</sub> SO <sub>4</sub>	kg/t	1,69
Water based ink for flexo printing	kg/t	1,82
Varnish for printing	kg/t	0,61
Ligno sulphonate	kg/t	0,63
Lubricants	kg/t	0,09
MgO	kg/t	0,03
NaClO <sub>3</sub>	kg/t	0,02
Na <sub>2</sub> CO <sub>3</sub> (soda)	kg/t	0,28
Na <sub>2</sub> SO <sub>4</sub>	kg/t	
NaOH	kg/t	2,37
NH <sub>3</sub>	kg/t	0,34
Oxygen, O <sub>2</sub>	kg/t	0,29
PAC (polyaluminiumchlorid)	kg/t	0,00
Pitch despergents	kg/t	0,29
Polymer and retention agents	kg/t	1,09
S	kg/t	0,11
Sizing agents	kg/t	2,40
SO <sub>2</sub>	kg/t	0,00
Starch, corn	kg/t	28,40
Starch, potato	kg/t	0,21
Starch, wheat	kg/t	31,50
Starch, modified	kg/t	3,70

**PACKAGING MATERIALS**

Pallet	kg/t	na
Paper, board	kg/t	7,59
PE	kg/t	0,68
Steel	kg/t	
Strapping	kg/t	0,48



**EMISSIONS TO AIR**

Dust	kg/t	0,02
Particulates, < 2,5 µm	kg/t	0,00
Particulates, > 2,5 µm, and < 10µm	kg/t	0,00
Particulates, > 10 µm	kg/t	0,00
CO <sub>2</sub> (fossil)	kg/t	341,85
CO <sub>2</sub> (biomass)	kg/t	293,99
CO	kg/t	0,38
NO <sub>x</sub> (as NO <sub>2</sub> )	kg/t	0,58
SO <sub>x</sub> (as SO <sub>2</sub> )	kg/t	0,15
TRS (H <sub>2</sub> S as S)	kg/t	0,00

**EMISSIONS TO WATER**

Water output	m <sup>3</sup> /t	
Thermally polluted	m <sup>3</sup> /t	3,35
Process water after treatment	m <sup>3</sup> /t	9,19
total	m <sup>3</sup> /t	12,64

**Waterborne emissions**

COD	kg/t	1,99
BOD <sub>5</sub>	kg/t	0,62
TOC	kg/t	0,83
Suspended solids	kg/t	0,62
Total Nitrogen	kg/t	0,13
AOX	kg/t	0,00
Total Phosphorus	kg/t	0,01

**RESIDUES***wet weight*

Calcium Carbonate	kg/t	1,51
Ink residues	kg/t	0,44
Inorganic ashes (10 01 01)	kg/t	7,04
Inorganic sludges	kg/t	1,02
Organic sludges (03 03 01 and 03 03 11)	kg/t	63,76
Paper for recycling **	kg/t	147,00
Rejects, paper related ***	kg/t	22,92
Rejects, other ****	kg/t	45,84
Starch, glue (wet weight)	kg/t	0,02
Lubricants and oil	kg/t	0,08

\* not representative

«0» no input or below reporting requirements see «chemical input»

«na» not available

\*\*The ratio of paper for recycling differs from the manufacturing model of a site. Corrugated sheet plants reach a ratio of 100kg paper for recycling per tonne of product. The additional 47kg paper for recycling are resulting from the conversion of a corrugated sheet into a finished product giving a total ratio of 1.147. Integrated corrugated packaging plants normally report a combined figure. The FEFCO corrugated packaging LCA was calculated in 2015 with the boundaries ending at the end of corrugating process, but including the impacts of printing. For all other years, the boundaries include the conversion of the corrugated sheet into a finished product.

\*\*\*Rejected materials that were associated with the previous use of the paper (for example, staples, paper clips, tags, adhesive labels, unrecovered fibres, etc)

\*\*\*\*Material that is not in anyway associated with the previous use of the paper (for example, foreign items such as plastic packaging, glass, sand and grit, etc)

\*\*\*\*\*Total fuel excluding Refuse Derived Fuel

## 5. Final Remarks

Both associations consider the project to be of major importance. To assure the maintenance of the database a Reference Group has been formed, with representatives from FEFCO and CCB. The main task of this Reference Group is to initiate updates and evaluate and develop the use of the database.

### 5.1. Updates

In the future a regular update of the database will be made, allowing an adaptation of the database to new developments in LCA standards.

The next update of the report is foreseen for 2021, based on 2020 data.

## 6. Definitions

Allocation	Technique for partitioning the inputs and outputs of a system amongst products.
Converted corrugated box	The corrugated board that is ready to use as a box. All shavings are accounted for.
Effluent	Water leaving the mill after treatment.
Incineration + energy	Incineration of residues with energy recovery.
Fluting	Paper grades used for the corrugated layer of corrugated board.
Functional additives	Additives that influence the properties of paper.
Liner	Paper grades used for the surface layer of corrugated board.
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
Life Cycle Impact Assessment	Phase of the life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.
Life Cycle Inventory Analysis	Phase of the life cycle assessment involving compilation, and the quantification of inputs and outputs, for a given product system throughout its life cycle.
Packaging materials	Materials bought and used for the packaging of the saleable product (wrappings, pallets).
Primary Fibre	Virgin fibre, fibres that have not been recycled before use in paper production.
Process additives	Additives that are used to guarantee that the process of paper production runs smoothly or to increase the production.
Rejects	Material in recovered paper, which is eliminated during pulp preparation.
Shavings	The total of all base paper cuttings that do not end up in the converted corrugated box (e.g. from corrugator trimmings, die-cuttings). Shavings are 100% recycled.
Tonne nsp (net saleable product)	1 tonne of paper/corrugated board product sold to the customer, including core plugs for the paper.
Transport distance of recovered paper	Distance from recovered paper supplier to the paper mill.
Transport distance of wood	Distance from harvesting site to the paper mill.
Recycled Fluting	Recovered fibre-based Fluting.

# Annex

The database may only be used for environmental studies regarding product development and improvement. **The database cannot be used for comparisons between the production of primary fibre and recovered fibre-based materials as such or for comparison to other materials.**

PRODUCT	tonne net saleable product	Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
		1	1	1	1	1
<b>Sold by products</b>						
Bark/wood	kg/t	0,00	3,51	0	0	0
Tall oil	kg/t	5,93	18,10	0	0	0
Turpentine	kg/t	0,58	1,30	0	0	0
<b>RAW MATERIAL</b>						
<b>Wood consumption</b>		<i>as bone dry weight (= 45% of transported total wet weight)</i>				
Softwood logs	t/t	0	0,86	0	0	0
Hardwood logs	t/t	0,83	0,14	0	0	0
Saw mill residues, softwood	t/t	0	0,11	0	0	0
Saw mill residues, hardwood	t/t	0,07	0	0	0	0
<i>Total wood</i>	<i>t/t</i>	<i>0,907</i>	<i>1,112</i>	<i>0</i>	<i>0</i>	<i>0</i>
<b>Recovered Paper</b>	<i>as wet weight</i>	0,0978	0,3640	1,08	1,08	0
Category						
Mixed Grades	t/t	0,0104	0,14	0,588	0,588	0
Corrugated and Kraft, pre-consumer	t/t	0,0338	0,036	0,1046	0,1046	0
Corrugated and Kraft, post-consumer	t/t	0,0532	0,18	0,343	0,343	0
Newspaper and Magazines	t/t	0	0	0,001	0,001	0
Other grades	t/t	0,0004	0,0012	0,0437	0,0437	0
<b>Purchased pulp consumption</b>		<i>as bone dry weight</i>				
Bleached pulp	t/t	0	0,0140	0,0007	0,0007	0
Unbleached pulp	t/t	0	0,0005	0,0002	0,0002	0
Other pulp	t/t	0,0006	0	0,0025	0,0025	
<b>Paper consumption for corrugated board production</b>						
Total	t/t	0	0	0	0	1,1
Coresh	kg/t	2,9*	1,6*	2,2*	2,2*	0
Core plugs	kg/t	0,045*	0,064*	0,04*	0,04*	0

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
<b>TRANSPORT OF RAW MATERIALS</b>						
<b>Wood</b>						
Wood with truck	t*km	580	407	0	0	0
Wood with rail	t*km	6	387	0	0	0
Wood with boat	t*km	0	1235	0	0	0
<b>Recovered paper</b>						
Recovered paper with truck	t*km	15	86	349	349	0
Recovered paper with rail	t*km	0	86	6	6	0
Recovered paper with boat	t*km	0	32	28	28	0
<b>Paper to corrugated board plants</b>						
Paper with truck	t*km	0	0	0	0	456
Paper with rail	t*km	0	0	0	0	326
Paper with boat	t*km	0	0	0	0	1733
<b>ENERGY INPUTS</b>						
<b>Steam</b>	GJ/t	0	0	0,482	0,482	0,026
<b>Bought Electricity</b>	GJ/t	0,731	0,958	0,625	0,625	0,460
<b>Fossil fuels</b>						
Natural gas	GJ/t	0,086	1,004	3,83	3,83	0,81
Heavy fuel oil	GJ/t	0,1897	0,168	0,0012	0,0012	0,015
Light fuel oil	GJ/t	0,0186	0,079	0,0076	0,0076	0,014
Diesel oil	GJ/t	0,0096	0,022	0,0006	0,0006	0,0099
LPG	GJ/t	0	0,105	0	0	0,035
Coal	GJ/t	0,3762	0,388	0,469	0,469	0,015
Lignite	GJ/t	0	0	0,089	0,089	0
Sulphur	GJ/t	0	0	0	0	0
Peat	GJ/t	2,43	0,005	0	0	0
<i>Total fossil fuel</i>	<i>GJ/t</i>	<i>3,107</i>	<i>1,77</i>	<i>4,39</i>	<i>4,39</i>	<i>0,899</i>
<b>Renewable fuels</b>						
Biofuel (bark, scrap wood, tall oil)	GJ/t	2,016	2,991	0,160	0,160	0,011
<i>Total renewable fuel</i>	<i>GJ/t</i>	<i>2,016</i>	<i>2,991</i>	<i>0,160</i>	<i>0,160</i>	<i>0,011</i>
<b>Refuse Derived Fuel</b>						
	GJ/t	0	0	0,18	0,18	0
<i>Total fuel**</i>	<i>GJ/t</i>	<i>5,12</i>	<i>4,76</i>	<i>4,55</i>	<i>4,55</i>	<i>0,91</i>

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
<b>WATER</b>						
<i>Input total</i>	<i>m3/t</i>	36,81	36,02	6,14	6,14	0,32
Ground water fossil/non-renewable	m3/t	0	0	1,19	1,19	0,016
Ground water non fossil/renewable		0	0,23	1,85	1,85	0,095
Surface water	m3/t	36,81	35,49	2,63	2,63	0,092
Municipal water supply	m3/t	0	0	0,42	0,42	0,28
Rain water		0	0,044	0,024	0,024	0
Other water received		0	0,253	0,025	0,025	0,0003
Water input-output		0,63	1,15	0,67	0,67	0,22
<b>PROCESS CHEMICALS AND ADDITIVES, DRY MASS</b>						
Alum (Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> )	kg/t	1,67	3,02	0,059	0,059	0
Biocides	kg/t	0,0006	0,099	0,146	0,146	0
Borax	kg/t	0	0	0	0	0,14
CaCO <sub>3</sub>	kg/t	0	4,82	0,365	0,365	0
CaO	kg/t	0,908	3,82	0	0	0
Coagulant	kg/t	0	0	0	0	0
Colorants	kg/t	0	0,825	0,63	0,63	0
CO <sub>2</sub>	kg/t	0	2,75	0,048	0,048	0
Defoamer	kg/t	0,016	0,205	0,267	0,267	0
Fillers	kg/t	0	8,23	1,72	1,72	0
Glue, cold + hot melts	kg/t	0	0	0	0	0,65
H <sub>2</sub> O <sub>2</sub> , peroxide	kg/t	0	2,49	0,0127	0,0127	0
H <sub>2</sub> SO <sub>4</sub>	kg/t	0,25	9,11	0,0133	0,0133	0
Water based ink for flexo printing	kg/t	0	0	0	0	1,82
Varnish for printing	kg/t	0	0	0	0	0,61
Ligno sulphonate	kg/t	0	0	0,67	0,67	0
Lubricants	kg/t	0	0,07	0,08	0,08	0
MgO	kg/t	1,11	0	0	0	0
NaClO <sub>3</sub>	kg/t	0	0	0,0224	0,0224	0
Na <sub>2</sub> CO <sub>3</sub> (soda)	kg/t	12,37	0	0	0	0
NaOH	kg/t	7,08	7,37	0,49	0,49	0,4
NH <sub>3</sub>	kg/t	12,32	0,119	0,035	0,035	0
Oxygen, O <sub>2</sub>	kg/t	0	1,56	0	0	0
PAC (polyaluminiumchlorid)	kg/t	0	0	0	0	0
Pitch despergents	kg/t	0	0,078	0,294	0,294	0
Polymer and retention agents	kg/t	0,0096	1,096	0,947	0,947	0
S	kg/t	4,69	0	0	0	0
Sizing agents	kg/t	0,034	0,707	2,41	2,41	0
SO <sub>2</sub>	kg/t	0,04	0	0	0	0



		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
Starch, corn	kg/t	0	2,48	18,55	18,55	10,50
Starch, potato	kg/t	0	0,99	0,0087	0,0087	0,02
Starch, wheat	kg/t	0	4,27	30,55	30,55	1,98
Starch, modified	kg/t	0	3,57	0,427	0,427	2,64
<b>PACKAGING MATERIALS</b>						
<i>not updated for paper production</i>						
Pallet	kg/t	0	0	0,01	0,01	na
Paper, board	kg/t	2,6	0,19	0	0	7,5
PE	kg/t	0,006	0	0,015	0,015	0,67
Strapping	kg/t	0	0	0	0	0,48
<b>EMISSIONS TO AIR</b>						
Dust	kg/t	0,163	0,089	0,004	0,004	
Particulates, < 2.5 µm	kg/t	na	na	na	na	0,001
Particulates, > 2.5 µm, and < 10µm	kg/t	na	na	na	na	0,0004
Particulates, > 10 µm	kg/t	na	na	na	na	0,0003
CO <sub>2</sub> (fossil)	kg/t	314,52	115,10	280,17	280,17	50
CO <sub>2</sub> (biomass)	kg/t	711,61	1351,28	31,56	31,56	0
CO	kg/t	1,10	1,53	0,08	0,08	0,003
NO <sub>x</sub> (as NO <sub>2</sub> )	kg/t	1,37	1,02	0,36	0,36	0,02
SO <sub>x</sub> (as SO <sub>2</sub> )	kg/t	0,566	0,293	0,069	0,069	0,015
TRS (H <sub>2</sub> S as S)	kg/t	0,055	0,016	0	0	0
<b>EMISSIONS TO WATER</b>						
<i>Water output</i>	<i>m<sup>3</sup>/t</i>					
Thermally polluted	m <sup>3</sup> /t	14,48	14,63	0,33	0,33	0,024
Process water after treatment	m <sup>3</sup> /t	15,88	20,20	5,26	5,26	0,18
<i>Total</i>	<i>m<sup>3</sup>/t</i>	<i>30,35</i>	<i>34,83</i>	<i>5,68</i>	<i>5,68</i>	<i>0,20</i>
<b>Waterborne emissions</b>						
COD	kg/t	5,05	5,60	0,88	0,88	0,01
BOD <sub>5</sub>	kg/t	0,245	2,066	0,246	0,246	0,003
TOC	kg/t	2,14	2,099	0,417	0,417	na
Suspended solids	kg/t	0,312	1,118	0,430	0,430	na
Total Nitrogen	kg/t	0,554	0,129	0,064	0,064	0,033
AOX	kg/t	na	0	0,0006	0,0006	na
Total Phosphorus	kg/t	0,008	0,015	0,0065	0,0065	0,0037
As	kg/t	na	0	0	0	na
Cu	kg/t	na	0	0	0	na
Cr	kg/t	na	0	0,0001	0,0001	na
Hg	kg/t	na	0	0	0	na
Ni	kg/t	na	0	0	0	na

			Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
Pb	*	kg/t	na	0	0	0	na
Zinc	*	kg/t	na	0	0,0001	0,0001	na
pH (year average)		pH	7,10	7,46	7,81	7,81	na
Temperature (year average)		oC	na	na	na	na	na
<b>RESIDUES, WET MASS</b>		<i>dry content</i>					
Calcium Carbonate	75%	kg/t	0,007	8,206	0	0	0
Ink residues	50%	kg/t	0	0	0	0	0,44
Inorganic ashes (10 01 01)	80%	kg/t	2,04	17,65	3,99	3,99	0
Inorganic sludges	65%	kg/t	1,35	5,39	0	0	0
Organic sludges	35%	kg/t	36,12	3,08	64,53	64,53	1,67
Paper for recycling	90%	kg/t	0	0	0	0	147
Rejects, paper related (03 03 07)	50%	kg/t	3,52	5,76	23,16	23,16	0
Rejects, other (03 03 07)	50%	kg/t	7,05	11,52	46,32	46,32	0
Starch, glue	30%	kg/t	0	0	0	0	0,02
Lubricants and oil	100%	kg/t	0,0095	0,14	0,02	0,02	0,03

\* limited data available

"0" no input or below reporting requirements see "chemical input"

"na" not available

\*\* total fuel excluding Refuse Derived Fuel

**FEFCO**  
Corrugated Packaging

**FEFCO**

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European Database for Corrugated Board Life Cycle Studies

