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D1.4 EUROPEAN FIBRE FLOW MODEL

Gert Meinl[1], Lydia Tempel[1], Jori Ringman[2] , Spyros Bousios[3]

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[1] PTS Papiertechnische Stiftung
[2] CEPI
[3] Bumaga BV

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SUMMARY

A material mass flow balance was developed for the region of CEPI member countries based on data collected and provided by CEPI. The most important challenge for modelling is the fact that an increasing portion of fibres are used repeatedly in papermaking cycles, i.e. unsold and consumed paper products are used again as raw materials.

The material mass flow balance allows calculating

- the average ash content in paper products and paper for recycling grades and
- the mean number of cycles. The fibres within a certain paper product used from the beginning to date or will be used from now until their end of life.

The ash content in paper for recycling grades influences the quality of paper products, especially their strength properties. Valid information about the future development of ash content in paper for recycling grades will enable paper mills to plan effective countermeasures in order to guarantee a constant product quality.

The number of cycles that a fibre is used repeatedly can be applied in allocation methods to share burdens of fibre extraction and end-of-life operations between different life cycles.

Based on a scenario how the mass balance inputs will change until 2020, changes in the ash content and the number of uses can be simulated.

1. Introduction

1.1 State of the art

The repeated use of fibres at a European level may be characterized by means of mass balances provided by CEPI (Figure 1). Similar mass balances are published on country levels by national agencies.

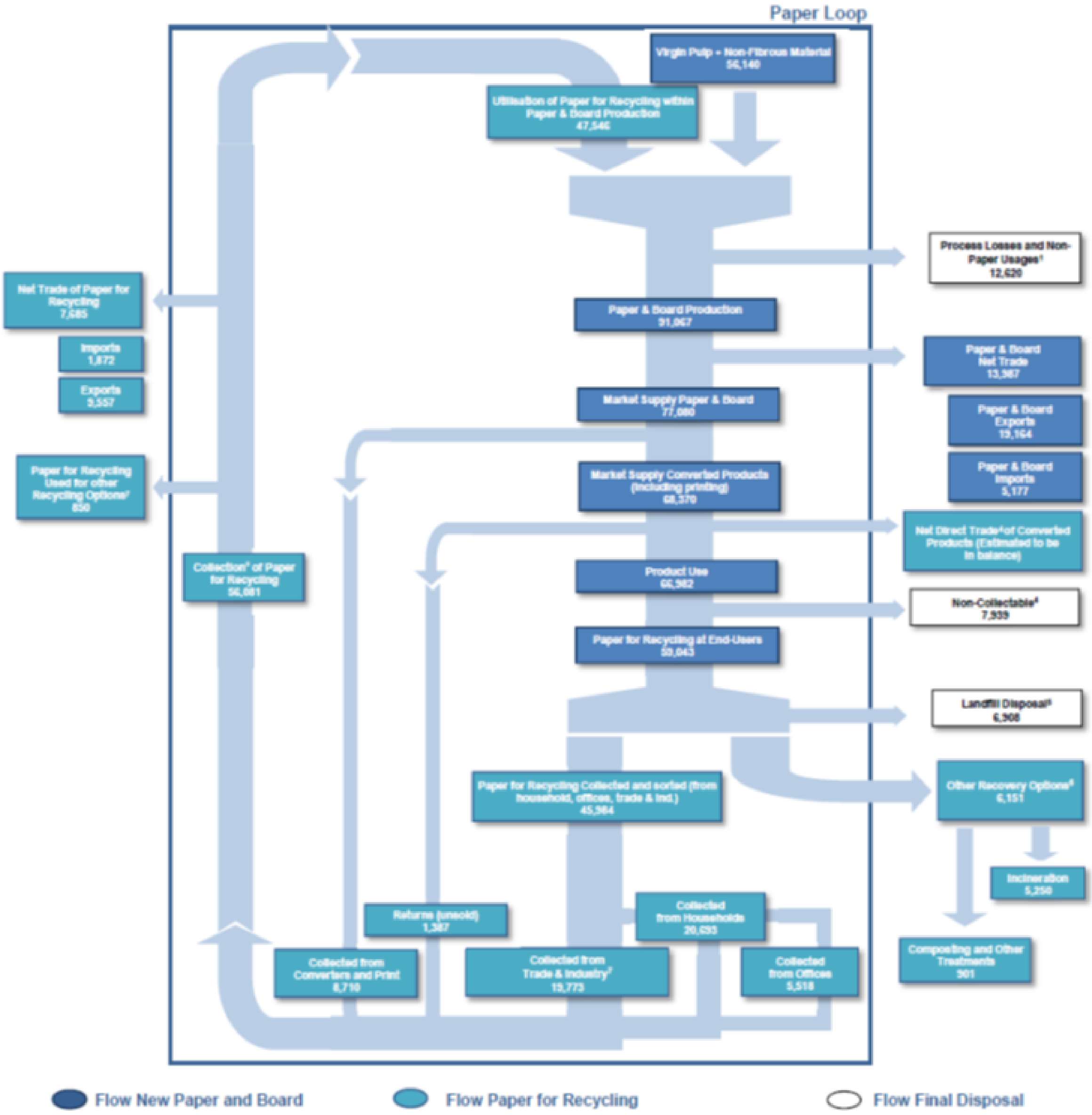

Figure 1: The European Paper Recycling Loop (CEPI 2014)

The average number of cycles a fibre is used in can be calculated from these mass balances. *Hunold* (1993) and *Göttsching* (1996, 2000) started a detailed analysis of recycling systems and provided some useful formulas for calculating fiber age values. For the loop in Figure 1 CEPI calculated, based on a model which is labeled by *Hunold* and *Göttsching* as One-Parameter-Model, 3.5 cycles *(CEPI 2013)*. The One-Parameter-Model simplifies a recycling system to only one loop with one input, the virgin fibres, and one output, the waste. The only principal parameter, which defines the fibre age of fibres, is the recycling rate.

Hunold and *Göttsching* analysed in their publications also more complex recycling systems (Two-Parameter-Modell, Multi-Parameter-Modell). However, all their calculations have only the fibre age in focus, which reflects only the past of the fibres life time. But for Life Cycle Assessment also information is needed, how many times a fibre will be used from now until end of their life.

Nevertheless, the work of *Hunold* and *Göttsching* was very valuable because they provided the basic mathematical approach. Surprisingly, since the work of *Hunold* and *Göttsching* in the 1990s, no substantial progress has been made.

1.2 Goal

The use of paper for recycling as raw material differs from paper product to paper product. Case materials and newspapers are nearly completely based on paper for recycling in many countries, whereas a certain amount of fresh fibres is necessary for high quality publication papers. Recycled newsprint and publication papers are then used as raw materials for packaging paper grades. As a result, the assumed single cycle must be divided into various connected sub cycles.

The paper production within a region of the CEPI member countries (18 member countries, 17 EU countries and Norway) can be divided into 6 major paper sectors:

- Newsprint (NP)
- Other graphic papers (OGP)
- Case materials (CM)
- Carton board (CB)
- Household/Sanitary (HS)
- Other paper and board (for technical applications) (OPB)

Paper products of the first four sectors are recycled and used a raw material in all 6 sectors. Paper products from the last two sectors are not recycled. They are assumed as unwanted materials in paper for recycling.

Based on a given data set provided by CEPI (2015a) it will be shown how a mass flow balance can be derived that takes the 6 major paper sectors and their connections due to recycling into account. Similar mass flow balances can be calculated if we assume some trends for paper production and consumption in the near future.

The numbers of fibre uses will be calculated via the mass flow balance. The method itself to calculate Mean Fibre Age resp. Mean Number of Future Uses is object of a separate publication (Meinl et al. 2016).

2. Methods

2.1 Fundamentals

Before calculating the mass balance some principal questions had to been answered:

- ***Level of regional differentiation:*** The mass balance will be established for the whole region of CEPI member countries.

- ***Level of differentiation into processes:*** Within a paper sector only production and consumption is taken into account

- ***Level of differentiation into materials:*** Only masses for fibres and fillers were used in the mass balance. Water (in terms of moisture), the different paper additives (like starch) and other non-fibrous materials, which are used in paper converting processes, are not summed up.

- ***Time scale.*** The mass balance is given on yearly base.
- ***Static or dynamic modelling:*** A steady-state mass balance will be established, i.e. the mass inputs and outputs at every point of the mass balance are equal.

2.2 Completing available statistics for European regions

Table 2 on the next page shows a typical data set available from CEPI for CEPI member countries. Obviously neither the use of virgin fibres nor the use of non-fibrous materials (fillers, coating pigments, starch and other) are known for individual paper sectors. It was noticed by CEPI that masses are given as typically used for trade purposes. Because the mass balance to be developed will be based on dry substances only, the moisture contents of raw materials and final paper products have to be taken into account based on the following average values:

- Graphical PfR: 8.6%
- Packaging PfR: 9.0%
- Virgin fibres: 10%
- Non-fibrous materials: 20%
- Paper products: 8.0%

The grey coloured fields in Table 3 on the next page contain the same data as Table 2 but now corrected into dry masses. The yellow coloured fields in Table 3 which are the unknowns in Table 2 (consumption of virgin fibres and non-fibrous materials per paper segment) have been now completed. Those data in the yellow fields are not calculable in a unique way based on the data in the grey fields. In fact, there are multiple solutions to complete the missing data. The data given in the yellow fields in Table 3 are based on following assumptions:

I. The amount of non-paper components in paper for recycling is zero

II. Material losses (i.e. the difference between material input and production) depend only on the amount of paper for recycling used per paper segment. Reasonable loss rates (i.e. loss per input volume of paper for recycling) are assumed and they are different for individual paper segments as shown in the Table 1:

Table 1: Loss rates for individual paper segments (Suhr 2015, Holik 2013)

NP	OGP	CM	CB	HS	OPB
21%	24%	7%	8%	37%	8%

III. The use ratio between virgin fibres and non-fibrous materials is constant

IV. 80% of non-fibrous materials are coating pigments or fillers; no use of inorganics for household/sanitary papers.

Table 3 contains three additional rows where a possible composition of non-fibrous materials is given according to assumption IV. Furthermore, summing up for each paper segment the masses for used paper for recycling grades, virgin fibres and non-fibrous materials and subtracting the production mass yields the production losses according to assumption II.

Table 2: Data set of the CEPI area for the year 2015 (CEPI 2015a). The numbers include the water as moisture in the materials.

		Used Grades of Paper for Recycling					Virgin Fibres (Total Pulp Consumption)				Non-Fibr. Mat		
		Mixed Grades	Corrugated & Kraft	Newspapers & Magazines	High Grades	**Total**	Mechanical	Chemical	Other	Tital	**Total**	Total Production	Total Consumption
		1.01/1.02	1.04/4.x	1.11	2.x/3.x								
Paper Sector	Sub group	kt	kt	kt	kt		kt	kt	kt	kt	kt	Mio. t	Mio. t
Graphic Papers	Newsprint	25	0	7.163	55	**7.244**	n.a.				n.a.	7.594	6.976
	Other Graph	154	18	2.766	706	**3.643**						29.328	22.388
Packaging Papers	Case Materi	4.829	18.551	265	835	**24.480**						26.204	24.801
	Carton Boar	3.583	2.466	307	1.328	**7.683**						17.047	12.986
Household & Sanitary		298	103	582	1.916	**2.899**						7.001	6.581
Other papers		255	1.049	126	166	**1.597**						3.892	3.538
		9.144	**22.187**	**11.208**	**5.006**	**47.546**	**10.164**	**30.984**	**410**	**41.559**	**15.451**	**91.067**	**77.270**

Table 3: Data set of the CEPI area with completed (the yellow coloured fields) and corrected (the grey coloured fields) data to exclude water (included dry mass only).

		Used Grades of Paper for Recycling					Virgin Fibres (Total Pulp Consumption)				Non-Fibr. Mat			Non-Fibrous Materials		
		Mixed Grades	Corrugated & Kraft	Newspapers & Magazines	High Grades	**Total**	Mechanical	Chemical	Other	Tital	**Total**	Total Production	Total Consumption	Coat.Pig	Filler	Additives
		1.01/1.02	1.04/4.x	1.11	2.x/3.x									kt	kt	kt
Paper Sector	Sub group	kt	kt	kt	kt		kt	kt	kt	kt	kt	Mio. t	Mio. t			
Graphic Papers	Newsprint	23	0	6.547	50	**6.620**	512	1.561	21	**2.093**	692	6.987	6.418	0	553	138
	Other Graph	140	16	2.528	645	**3.329**	4.610	14.052	186	**18.848**	6.229	26.982	20.597	2.492	2.492	1.246
Packaging Papers	Case Materi	4.395	16.882	242	763	**22.281**	810	2.470	33	**3.313**	1.095	24.108	22.817	876	0	219
	Carton Boar	3.260	2.244	280	1.214	**6.998**	1.769	5.391	71	**7.231**	2.390	15.683	11.947	1.912	0	478
Household & Sanitary		271	94	532	1.751	**2.648**	1.018	3.104	41	**4.163**	1.376	6.441	6.054	0	0	1.376
Other papers		232	955	115	152	**1.454**	429	1.308	17	**1.754**	580	3.581	3.255	0	464	116
Total		**8.321**	**20.191**	**10.244**	**4.576**	**43.332**	**9.148**	**27.886**	**369**	**37.403**	**12.361**	**83.781**	**71.088**	**5.279**	**3.509**	**3.573**

2.3 Calculating the migration of paper for recycling and establishment of the regional mass balance

The migration of paper products between different paper sectors and sub groups is determined by collection and sorting systems as well as by the recipes used for paper products based on paper for recycling. The easiest way to calculate the amount of products from one sub group used as paper for recycling in another sub group is analysing the composition of the paper for recycling grades given as raw materials in the CEPI data set. Unfortunately, these data are only available for some individual countries. For Germany the composition of the various grades is pictured in Table 4.

Table 4: Composition of paper for recycling grades in Germany based on Putz (2010)

PfR Grade	Newsprint	Other Graphic Papers	Case Materials	Carton Board
1.02	12%	46%	28%	14%
1.04	3%	16%	59%	22%
1.11	35%	61%	1%	3%

Unpublished composition data exist for a few other countries. Due to the lack of sufficient data it was decided to derive the composition of Paper for Recycling grades from available information about paper consumption and is shown in the Table 5.

Table 5: Composition of paper for recycling grades for the whole CEPI region (Red coloured field were calculated from given information of paper consumption; Green coloured field are pre-set values)

		Newsprint	Other Graphic Papers	Case Materials	Carton Board
Mixed grades	1.01/1.02	10%	43%	27%	19%
Corrugated / Kraft	1.04/4.x	0%	4%	65%	32%
Newspapers / Magazines	1.11	34%	63%	0%	3%
High grades	2.x/3.x	20%	76%	0%	4%

Combining Table 3 and Table 5 leads to an overview of paper product migration in Europe (Table 6).

Table 6: Paper products contained in the paper for recycling used for individual paper segments (based on Table 3 and Table 5)

2014					Paper Products in Paper for Recycling			
Paper Sector	Production (incl. Add.) kt	Consumpt. (incl. Add.) kt	Recycling Usage kt	Grade of Paper for Recycling	Newsprint	Other Graphic Papers	Case Materials	Carton Board
Newsprint	6.987	6.418	23	1.01/1.02	2	10	6	4
			0	1.04/4.x	0	0	0	0
			6.547	1.11	2226	4125	0	196
			50	2.x/3.x	10	38	0	2
			6.620	**total**	**2.238**	**4.173**	**6**	**203**
Other Graphic Papers	26.982	20.597	140	1.01/1.02	15	61	38	27
			16	1.04/4.x	0	1	11	5
			2.528	1.11	860	1593	0	76
			645	2.x/3.x	129	490	0	26
			3.329	**total**	**1.003**	**2.144**	**48**	**134**
Case Materials	24.108	22.817	4.395	1.01/1.02	457	1905	1184	850
			16.882	1.04/4.x	0	604	10921	5357
			242	1.11	82	152	0	7
			763	2.x/3.x	153	580	0	31
			22.281	**total**	**691**	**3.241**	**12.105**	**6.245**
Carton Board	15.683	11.947	3.260	1.01/1.02	339	1413	878	630
			2.244	1.04/4.x	0	80	1452	712
			280	1.11	95	177	0	8
			1.214	2.x/3.x	243	923	0	49
			6.998	**total**	**677**	**2.592**	**2.330**	**1.399**
Household	6.441	6.054	271	1.01/1.02	28	117	73	52
			94	1.04/4.x	0	3	61	30
			532	1.11	181	335	0	16
			1.751	2.x/3.x	350	1331	0	70
			2.648	**total**	**559**	**1.787**	**134**	**168**
Other Papers	3.581	3.255	232	1.01/1.02	24	101	63	45
			955	1.04/4.x	0	34	618	303
			115	1.11	39	72	0	3
			152	2.x/3.x	30	116	0	6
			1.454	**total**	**94**	**323**	**680**	**357**
Gesamt	**83.781**	**71.088**	**43332**		**5263**	**14260**	**15303**	**8507**

2.4 Mass balance

A complete mass balance of the CEPI area (Figure 2) can be derived from Table 6. In contrast to Figure 1 the whole recycling system was divided into 4 recycling loops (Newsprint, Other Graphic Papers, Case Materials and Carton Board) and 2 not recycled paper grades (Sanitary/Household and Other Paper and Board). Additionally, all 4 recycling loops are connected each other, i.e. products from one cycle are used after recycling due to migration as raw material in the other cycle and for production of Household/Sanitary Papers and for Other Paper and Board. All 6 paper sectors have separate entries (Virgin fibres and Filler/Pigments). All 6 paper sectors have also various exits. For the 4 recycling loops the exits are the net trade of paper products and paper for recycling and the losses due to disposal and long-time usage. The export and import of these materials outside the statistics are not taken into account in this study. For all 6 paper sectors a separate exit is defined by rejects of paper production.

In the mass balance only fibres, fillers and pigments are taken into account, while additives are ignored. Production and consumption and also Paper for Recycling utilisation in Table 6 is inluding additives. The mass volumes in Figure 2 have been subtracted by the addives according to Table 6.

2.5 Calculating the ash content

Based on the mass flow balance in Figure 2 the ash content at every point of the flow chart can be calculated easily. The mass flow consists of two materials namely fibrous (organic fibres and fines) and non-fibrous (pigments, fillers) materials. Calculating the composition of a mixture of multipole mass flows is trivial.

If a mass flow is separated into multiple single mass flows one should consider the way of separation. If the mass flow is separated as a result of paper collection or sorting the composition in terms of fibrous and non-fibrous components is assumed to be equal for every single mass flow. The separation process in a paper mill is more selective because it is focused on discharging non-fibrous components from paper for recycling. For simplification it was assumed, that all rejects (except for production of tissue) contain 40% non-fibrous materials. If paper for recycling is used for production of sanitary or household papers it was assumed an average content of 20% of non-fibrous materials in rejects.

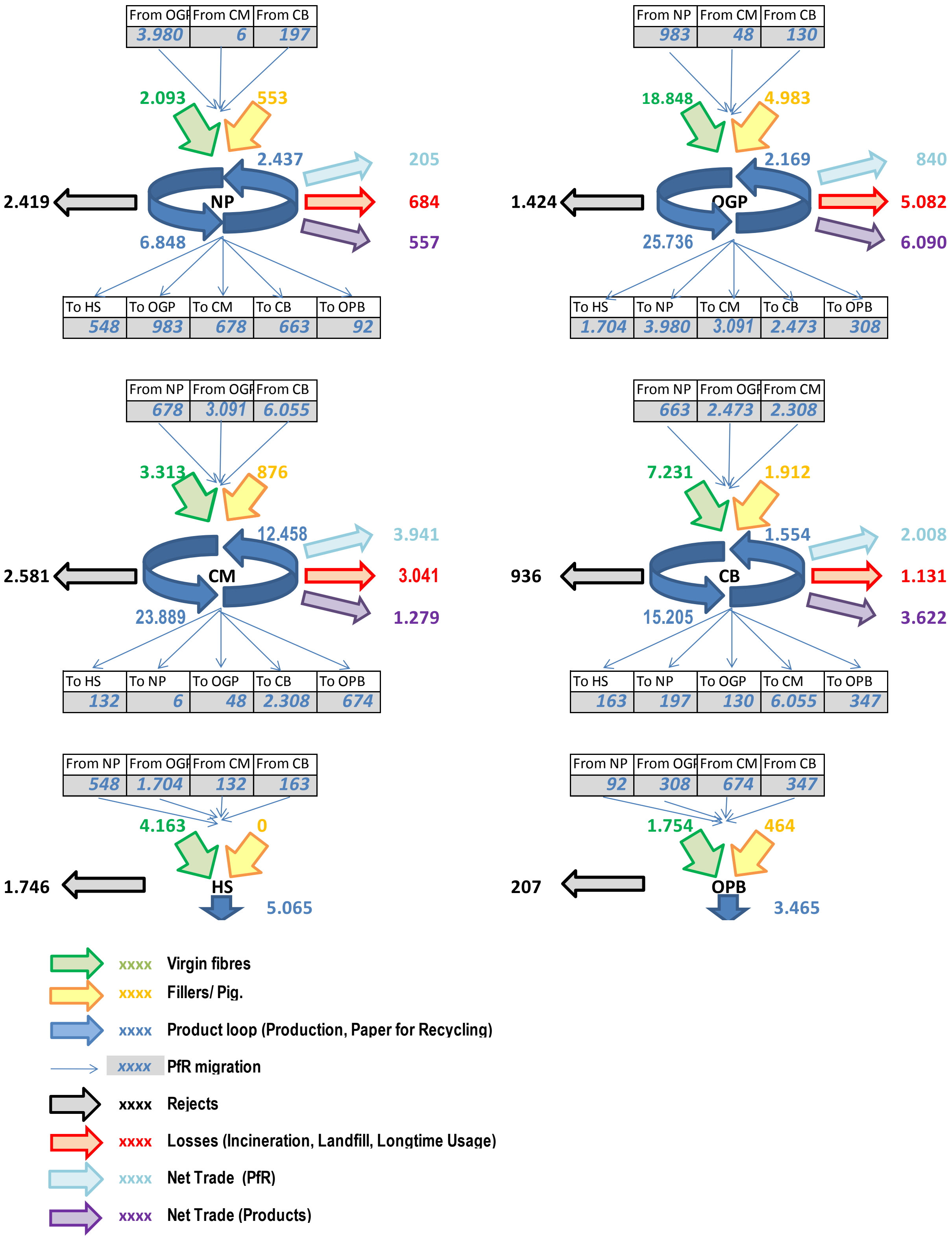

Figure 2: Mass balance for the whole CEPI area (Paper consumption is not visualized explicitly)

2.6 Calculating key parameters of the mass flow balance

The key parameters of the mass flow balance for every individual recycling system are

- The Recycling Rate *R*: Percentage of PfR “utilisation + net trade” compared to total paper & board consumption
- The paper for recycling Utilisation Rate *U*: Percentage of PfR utilisation compared to the total paper production
- The Reject Rate *L*: Percentage of losses compared to PfR utilisation
- The Mean Fibre Age *MFA:* Mean number of generations a fibre was used to date within a certain paper product)
- The Mean Number of Future Uses *MNU*: Mean number of future repeated uses of a fibre starting from the current paper product until the end of their life

For the calculation of *MFA* and *MNU* according to *Meinl* (2016) the mass flow balance should be transferred into an ordered and weighted graph, a so called network (Figure 3).

Every paper sub group is represented by node of the network. The sources are the virgin pulps whereas rejects, net trades and losses are summed up into sinks. The original mass flows in the mass flow balance are transferred into exit resp. entry weights (Table 7). These weights can be interpreted as likelihoods that a fibre within a paper grade originates from a certain recycled paper grade resp. will be recycled into another paper grade.

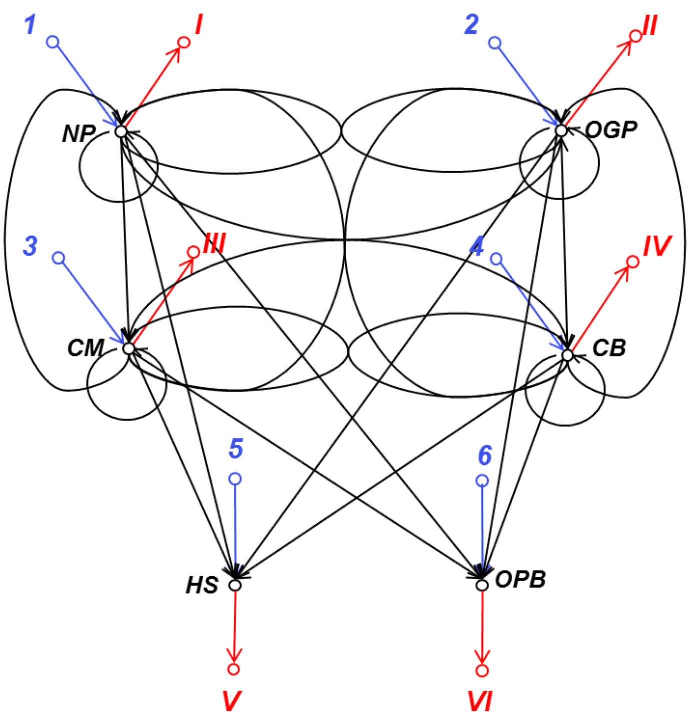

Figure 3: Multi-parameter model in terms of an oriented graph for the CEPI region. Arabic numerals represent the sources and Roman numeral the sinks

Table 7: Exit and Entry weights of the network (Figure 3)

Nodes		Weights	
Starting Node	**End Node**	**Exit Weight**	**Entry Weight**
NP	I	1.00	0.36
1	NP	0.27	1.00
NP	NP	0.29	0.29
NP	OGP	0.04	0.12
NP	CM	0.03	0.08
NP	CB	0.05	0.08
NP	HS	0.08	0.07
NP	OPB	0.03	0.01
OGP	II	1.00	0.48
2	OGP	0.87	1.00
OGP	NP	0.42	0.15
OGP	OGP	0.08	0.08
OGP	CM	0.11	0.12
OGP	CB	0.15	0.09
OGP	HS	0.04	0.07
OGP	OPB	0.09	0.01
CM	III	1.00	0.39
3	CM	0.15	1.00
CM	NP	0.00	0.00
CM	OGP	0.00	0.00
CM	CM	0.48	0.48
CM	CB	0.15	0.09
CM	HS	0.02	0.01
CM	OPB	0.20	0.03
CB	IV	1.00	0.47
4	CB	0.55	1.00
CB	NP	0.02	0.01
CB	OGP	0.00	0.01
CB	CM	0.23	0.38
CB	CB	0.10	0.10
CB	HS	0.02	0.01
CB	OPB	0.10	0.02
5	HS	0.65	1.00
HS	V	1.00	1.00
6	OPB	0.59	1.00
OPB	VI	1.00	1.00

2.7 Future scenario for paper production and recycling

In order to derive a scenario for future paper production and recycling the paper production of the 6 major paper sectors was analysed (Figure 4).

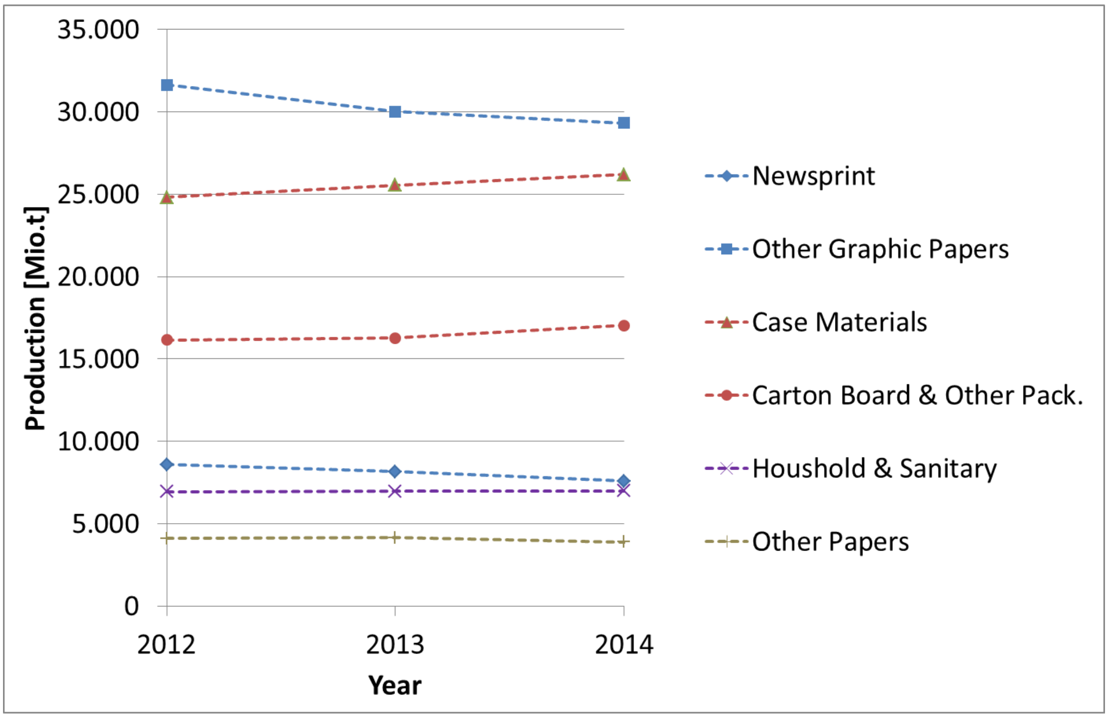

Figure 4: Development of Paper production in the 6 major paper sectors (CEPI 2015b)

For a calculation of a mass balance in 2020 it was assumed that the yearly development rate of production in each paper sector equals the average yearly development rate from 2012 to 2014 (Table 8).

Table 8: Assumed yearly development rate of paper production and consumption for all 6 major paper sectors

Paper sector	Sub group	Yearly development rate
Graphic Papers	Newsprint	-5.7%
	Other Graphic Papers	-2.4%
Packaging Papers	Case Materials	2.4%
	Carton Board	3.6%
Houshold & Sanitary		-0.3%
Other Paper and Board		-3.3%

For deriving a future mass balance the data in Table 3 will be changed proportionally according to the development rates in Table 8. No changes in the basic recipes for the paper grades are assumed. Even though new technologies can result in higher ash content (see section 2.8) for all calculations a constant ratio of filler and pigment application was stated.

2.8 Technologies influencing the inorganic content

Inorganic fillers are the most important components used in papermaking after cellulosic fibres, their significance being attributed to both their influence on the optical properties, bulk and smoothness of the end product and effect on the economics of the process. The latter manifests itself in two ways, namely the partial substitution of much more expensive fibres as well as the improved drainage on the paper machine wires, which saves costs for drying energy. These positive economic aspects of fillers make the production of papers with higher filler contents an attractive business alternative for paper producers; its realisation involves, however, significant limitations primarily due to the negative effects of fillers on mechanical properties. Fillers disrupt the network of fibre-fibre bonding in the sheet by reducing the number of fibres and preventing the effective contact between fibrils. Higher filler levels reduce also the efficiency of conventional dry-strength agents. Because of these drawbacks, it is very important to identify strategies for counteracting the deterioration of strength properties.

One of the strategies proposed involves the chemical modification of filler surfaces in order to achieve better fibre-filler-fibre bonding *(Lourenço et al., 2014)*. Precipitated calcium carbonate (PCC) has been modified with a wide range of (primarily) organic compounds, ranging from starch to polymer latexes. An indicative example of work in this direction is the investigation of silica-coated PCC by *Lourenço et al., 2014.* For similar filler contents (16-40%), the use of silica-coated filler was found to improve the main paper strength properties of handsheets made of eucalyptus kraft pulp compared to common PCC. The results were interpreted as indication that this type of modified filler can enable the production of papers with higher filler contents.

Another example of filler modification, which was aimed at keeping the modification costs as low as possible, has been offered by *Ragauskas et al.* This work focussed on the modification of clay fillers by means of starch coating. The starch-coated clay was found to increase paper strength by 10-15% relative to unmodified clay, thus showcasing significant potential for the production of paper with high filler contents while utilising even low grade starch.

Besides filler modification, another method has been proposed, for avoiding the adverse effects of higher filler contents on mechanical properties: the pre-flocculation of fillers prior to their addition to the wet end approach system. Pre-flocculation is aimed at forming filler agglomerates and effectively increases filler size while reducing filler surface area. This reduces the disruptive effect of fillers on fibre-fibre bonding. The FillerTEK technology of the company Nalco is already commercially available for filler pre-flocculation (for PCC, GCC [ground calcium carbonate] and blends thereof). *Cheng et al. (2011)* have presented results from full-scale trials using this technology and demonstrating an increase in sheet ash from 18% to 23% in a North American fine paper machine (wood-free uncoated paper) and by 3-5% in an Asian paper machine producing coated wood-free paper.

Developments aimed at increasing the filler content of paper products can also be found in the field of retention systems. Kemira, for example, has developed the Kemform retention system, which is based on micropolymers. A number of mill trials have demonstrated that this system has the potential for increasing the filler content. 2% higher ash contents were achieved during these trials in both uncoated fine paper from bleached kraft pulp and uncoated fine paper from bleached kraft pulp and bleached chemi-thermomechanical pulp *(Hietaniemi et al.).*

Improved retention systems also played a role in a known case of commercial paper production with higher filler content. In 2011 the former M-real (currently Double A) Alizay mill in France reached a filler content of 35% (up from 23%) in copy paper made from kraft pulp (*Rodden, 2012).* This result was achieved by the combined use of a strength additive (supplied by Ashland) that builds a polymeric network between fibres and fillers in order to maintain sheet strength, a non-modified PCC filler with a morphology that helps maintain bulk and stiffness, and a retention system (also by Ashland) composed of a micropolymer-based retention additive, polyacrylamide flocculant and aluminium source for maintaining ash retention.

Another strategy for producing paper with higher filler contents that receives significant attention is the utilisation of nanocellulose. Imerys, for example, has developed the FiberLean microfibrillated cellulose (MFC) product, the use of which is supposed to lead to a 10-15% reduction in cellulose fibre use in base paper; highly filled sheets made with 4% of this MFC product have reached 55% GCC (*Imerys 2016*). These results are attributed to the large surface area of the MFC, which enables the formation of more hydrogen bonds within the web and gives natural strength to the paper. Indicative results of the use of FiberLean MFC include the following:

+13% GCC in 130 g/m^2 coated wood-free paper,

+17% GCC in 300 g/m^2 coated wood-free paper,

+10% PCC in 75 g/m^2 uncoated wood-free paper

Kajanto and Kosonen (2012) have demonstrated that the addition of small amounts (1-2%) of nanofibrillated cellulose (NFC) in 50-65 g/m^2 paper made from chemical pulp results in tensile strength gains that permit an 8 g/m^2 reduction in basis weight. This strength increase can be utilised for both the production of stronger packaging papers and boards and the production of graphic papers with higher filler contents. *Taipale et al. (2010)* also found that the addition of MFC to a pulp suspension improves paper strength properties, especially when combined with a cationic polyelectrolyte fixative. *Subramanian et al. (2011)*, finally, have proposed that a microfines-filler furnish is more effective than a fibre-filler furnish in achieving higher filler contents in paper. They proposed the utilisation of a microfines-filler composite in uncoated fine paper, where the microfines (15-30%) offer strength properties, the filler (up to 60%) offers bulk and porosity, and tear strength is ensured by the minimal presence of a fibre fraction (10-20%).

In general four different types of technologies to increase filler content are proposed – chemical modification of fillers, pre-flocculation of fillers, improved retention systems and micro/nanocellulose utilization. The technologies and corresponding results are summarised in Table 9.

Table 9: Summary of methods proposed for increasing the inorganic content of various paper products

Type of technology	Result
Chemical modification of fillers	Strength increase at similar filler contents relative to non-modified fillers
Pre-flocculation of fillers	+5% fillers in wood-free uncoated paper, +3-5% in wood-free coated paper
Improved retention systems	+2% fillers in uncoated fine paper, +10% fillers in copy paper (in combination with other measures)
Micro/nanocellulose utilisation	>+10% fillers in coated/uncoated wood-free paper, strength increase in 50-65 g/m^2 paper

3. Results

3.1 Mass balance 2020

Based on the assumed yearly production and consumption development rates a mass balance for the CEPI region for the year 2020 was derived (Figure 5)

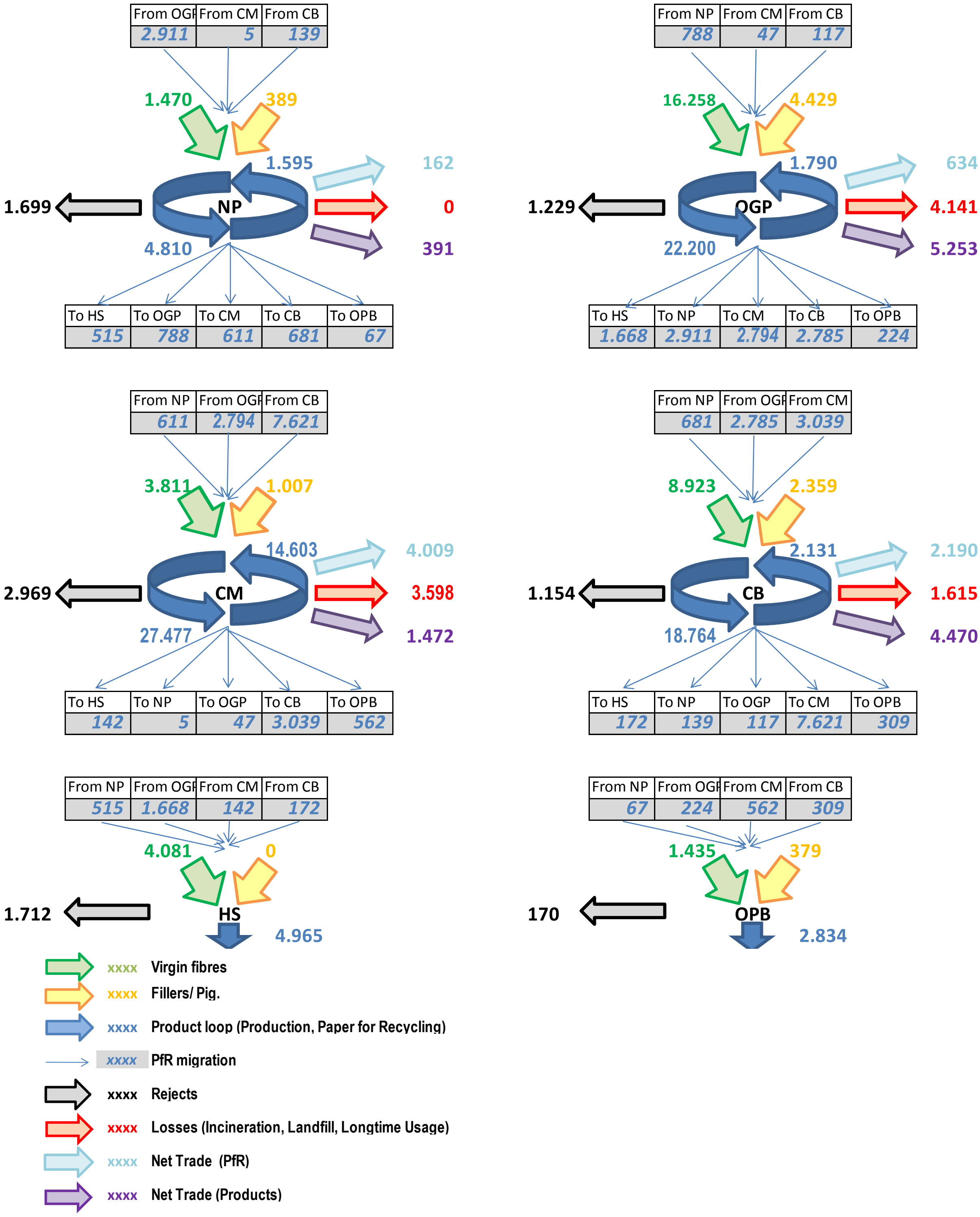

Figure 5: Predicted mass balance for CEPI region in the year 2020 based on assumed yearly development rates from Table 8

3.2 Key parameters of the mass balance

Based on the mass balance in Figure 2 the key parameters can be calculated and are presented in Table 10.

Table 10: Key parameters of mass flow balance for CEPI region 2014

	Ash	*MFA*	*MNU*	*U*	*R*	*L*
NP	9%	2.00	4.20	0.97	0.89	0.37
OGP	19%	1.14	3.01	0.13	0.75	0.43
CM	14%	3.02	3.09	0.93	0.87	0.12
OP	17%	1.85	2.79	0.46	0.90	0.13
HS	17%	1.25	1.00	0.49	0.00	0.66
OPB	15%	1.86	1.00	0.32	0.00	0.14

The predicted mass flow balance in Figure 5 yields the following key parameters that are shown in the Table 11.

Table 11: Key parameters of the predicted mass flow balance for CEPI region 2020

	Ash	*MFA*	*MNU*	*U*	*R*	*L*
NP	10%	1.97	4.92	0.97	1.00	0.37
OGP	20%	1.13	3.15	0.12	0.76	0.45
CM	14%	3.07	3.11	0.93	0.86	0.12
OP	18%	1.87	2.77	0.46	0.89	0.13
HS	17%	1.24	1.00	0.49	0.00	0.66
OPB	15%	1.88	1.00	0.31	0.00	0.14

4. Discussion

4.1 Ash content development due to changing production output

According to the assumed mass balance for the year 2020 the average ash content in the paper grades will increase by up to 1%. The newsprint production is the major de-ashing stage in the whole recycling system. The assumed yearly development rates shown in Table 8 mean that the large decline of newsprint production in contrast to the more moderate decline of the production of other graphic papers induces that a lower portion of graphic papers, which will finally be used as secondary raw material for all other paper grades, will be de-ashed.

4.2 Mean Fibre Age / Mean Number of Future Uses

High values of *MFA* (for CM and NP) express high paper for recycling utilisation rates and this will not change remarkably over the next years. The small drop down for NP and OGP in the next years is due to the change of composition of paper for recycling grade used for graphic paper production. Less newsprint but a higher share of other graphical papers will become typical. High values of *MNU* (NP, OGP and CM) reflect the close recycling loop for those paper grades. The other grades are used over longer periods (CM) or are not recycled (HS and OPB). Fibres which have been ever used in newsprint will be used more than a half generation more in 2020 than today because of their increased “chance” to be used afterwards as raw material for the growing market of packaging papers instead for graphic papers. We can be sure that recycled newsprint fibres will be a valuable raw material for packaging papers and their recycling rate *R* will increase (see 4.3).

The total numbers of uses, i.e. *MFA+MNU*-1, of fibres when used at least one time for Newsprint or Case Material production are the highest ones (about 5.1 to 5.2). This is mainly caused by the high paper for recycling utilisation and recycling rates. With values of 3.2 resp. 3.6 the total numbers are lower for those fibres, which are used for production of other graphic papers resp. carton board and other packaging papers. Not surprisingly the total numbers are low (1.3 for HS and 1.9 for OPB) when the fibres are used for production of sanitary and tissue papers or for other technical papers.

4.3 Recycling rate

For the first time a recycling rate for individual paper grades can be given. CEPI has calculated an average recycling rate of 71.2% over all paper grades. Because household and sanitary papers and all the other technical papers are not recycled, the recycling rates for the other 4 paper sectors must be considerably higher, ranging from 75% (other graphic papers) to 90% (case materials). Very likely the recycling rate for other graphic papers can be higher because a substantial amount of those papers are used over an even longer period than typically for the other graphical and packaging paper grades.

According to the modelling the recycling rate of newsprint will reach 100% in 2020. This calculated value becomes realistic if we take into account the increasing competition of packaging paper producing mills for paper for recycling grades with lower ash content and lower fibre age. Both quality parameters enable packaging paper producers to guarantee a given strength level without any cost expansive technical or chemical measure.

4.4 Total number of uses vs. maximal number of uses

The value *MFA(X)+MNU(X)*-1 represents the total average number of uses of a fibre when used at least one time in product *X*. As already mentioned in 4.2 this number ranges from 1.3 (HS) until 5.2 (NP). It must be emphasised that this value is based totally on a mass balance of a given recycling system and should be not confused with the maximal possible number of uses as far as a fibre has sufficient bonding ability. The intensity of processes during re-pulping and the quality requirements for the final paper product will clearly influence this maximal possible number. In private communications it was assumed that up to 6-8 cycles a fibre can be used for case materials. If this is true there is still some space left for higher recycling rates.

4.5 Reliability of the key parameters

The calculated values for *MFA*, *MNU*, *U, R* and *L* in Table 10 and Table 11 depend solely on the mass balances shown in Figure 2 and Figure 5. Unfortunately no other values from independent sources are available to check the reliability of the values. As mentioned in sections 2.2 and 2.3 some assumptions have to be made to fill gaps in the data set provided by CEPI (Table 2). For instance the assumptions concerning moisture content of raw materials and final products influence directly the amount of process losses, i.e. the difference between the mass of used materials and the mass of final products. The high value of *L* in Table 10 and Table 11 for graphical papers and household & sanitary papers is possibly an indicator that the assumptions need to be reviewed. Corresponding research activities are going on and will lead finally to an improved mass balance and in consequence the absolute values of *MFA, MNU* and other key parameters will change. But the basic trend from 2014 (Table 10) to 2020 (Table 11) will remain even if the assumptions will be changed.

5. Conclusions

For the first time based on data of paper production and recycling of a given region a mass balance for the region was established which allows the calculation of key parameters that characterise utilisation and recycling of papers in a more detailed way. Beside the information for paper mill how the quality of paper for recycling will develop in the next future the approach allows to provide fundamental data for making a fair Life Cycle Assessment and solving the allocation problem in Open-loop recycling systems. A separate publication within the REFFIBRE project will deal with this topic.

Some well-known basic facts were not included in the models because reliable data are scarce.

- Paper products are exported and imported by the CEPI member countries. According to CEPI (2015) about 19 Mio. t of the produced paper quantity of 91 Mio. t goes outside CEPI (mainly Russia and Asia) and about 5 Mio.t of the consumed paper quantity of 77 Mio. t comes from outside CEPI (mainly Russia and North America). The quality of imported paper products (ash content, mean fibre age) can differ from those circulating within the CEPI region. But in the current mass flow model it is assumed that imported and local grades of paper are of the same quality.

- Europe exports about 9 Mio. t of paper for recycling to Asia (CEPI 2015). This material comes back to Europe as packaging for goods. Such global recycling cycles have not been modelled but there are research efforts underway to quantify those material flows.

- Calculations for 2014 and 2020 were made under steady-state conditions, i.e. all input values were changed in one step with no delay in the corresponding response. In reality the mass balance input values change continuously with time lags between the dependent variables. Typically, a system of this type reacts in the form of oscillations (and very likely over a long period) to any change in input values.

Nevertheless, the selected approach to calculate detailed key parameters for the recycling system of the CEPI member countries can be applied for arbitrary regions. For demonstration some calculations have been made for single European regions within the REFFIBRE project. They show remarkable differences between the regions. But the smaller the regions of interest become the more important becomes the consideration of import and export relations between the regions. This is still a topic of future research.

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