The Myth of Limited Fibre Life Cycles

On the potential of paper fibre

To conduct experiments with closed loop recycling, more than 3000 lab sheets had to be produced.

Summary

Paper and cardboard are primarily made from recycled fibres. A sustainable paper industry is no longer conceivable without recycling. Hence, the question of how often paper fibres can even be recycled is quite justified. As simple as this question might appear, the answer is not trivial. The answer that is summarised in our fast-paced age that paper fibres can be recycled 4-7 times, doesn't contain much truth following our ongoing repetitions. This article refutes at least part of this statement with literature research. Current in-house research shows what paper fibres are truly capable of and that the categorical statement on the rather limited life span of fibres is inaccurate.

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Keywords
Recycling, closed loop recycling, fibre life cycles, fibre lifespan, fibre age

Motivation
According to Wikipedia, myths have a claim to validity for the truth they claim. In a further sense, **myth** also described people, things or event of a higher symbolic meaning or also simply an incorrect concept or lie. The previous answers to questions about how often paper fibres can be recycles could certainly be considered a myth that does not become any more correct due to the fact that an incorrect answer keeps being repeated. The question remains: where does this statement come from and who is copying whom?
The answers to be found for the maximum possible number of recycling cycles for fibres lie mostly in the range of 4 to 7 times. This range continues to be put out there without a clear source ever being named. Loss of quality, loss of stability or shortening of fibres are often given as reasons for the limited longevity. In one of the reference books, it is even stated that virtually no substrate of unbleached pine sulfate pulp was available to form sheets on an experimental paper machine after 7 processes, because due to limited first-pass retention,

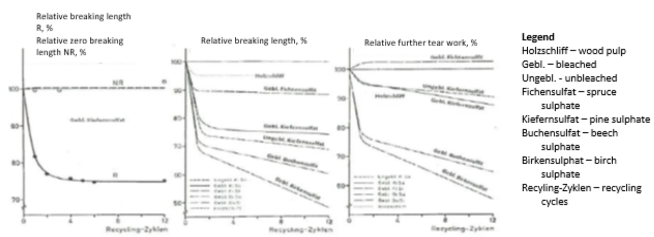

Fig. 1 Relative strength progression of various pulps depending on number of recycling loops (comminution only prior to first cycle; cellulose 37-41 SR; grinding 61 SR)

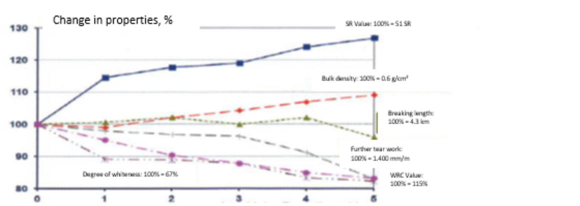

Fig. 2: Change in properties by percent in closed loop recycling of newsprint

even with an almost closed water circuit, the pulp originally suitable for sheet formation was lost with the waste water as fine material. However, this statement cannot be found the in indicated source and it is very suspicious that the pulp was literally 'ground to death'.

Fundamentals for successful recycling
Even if the starkly limited number of fibre recycling cycles is to be doubted, some of the statements from the previously cited sources are correct and required for functional and sustainable paper recycling. In a national economy such as Germany, for example, with a highly diversified paper production programme, recycling can only function if there is a constant supply of primary fibres. The reasons for this lie in the fact that not all paper products can be supplied to material recycling, on the one hand. Generally, it is assumed that this is the case for about 19% of paper consumption, especially all paper and cardboards for technical and special purposes, as well as all hygienic papers. On the other hand, there are always losses of fibre and fine material that must be replenished by primary fibre material. Without this input of fresh fibre, a closed paper recycling circulation system would collapse within a measurable period due to the lack of mass. To this extent, the calculation of the quantity-based circulation of fibre that is on average 3.6 in 2016 is correct for the European market, but this says nothing about the maximum recycling count that is technologically possible. It is certainly also true that fibres recycled multiple times are not necessarily 'improved' by the process of recycling. However, the degree of the ever-assumed loss of stability is dependent on the material and limited.

State of knowledge
Scientific examinations on the recycling behaviour of various pulps according to type of wood and pulping processes were being conducted in the 1970s. In extensive lab simulations with up to 12 recycling processes, Stürmer and Göttsching have shown that pulps (chemical and mechanical) behave quite differently as part of the recycling process (Fig. 1). Whilst lignin-rich mechanical pulp barely loses any of its original level of firmness over the course of repeated recycling, lignin-free cellulose clearly behaves differently. It only significantly loses firmness within the first three to four cycles of recycling, changes thereafter are marginal. Other authors have reached similar conclusions. However, direct comparisons are usually not possible, as the background of the investigated original materials (pre-dried or not) is not always clearly defined or the type of sheet formation (with or without recirculation water) and drying (temperature level, with or without vacuum or shrinkage restraints) cannot be precisely described or simply present differently. It is, however, conspicuous that there are no investigations on the recycling behaviour of waste paper in the sense of raw material as a blend of secondary fibres of varying 'ages' for the manufacture test liner and corrugated board. There are also hardly any publications for the classic primary materials for kraftliner, i.e., unbleached sulphate pulp, and semi-chemical pulp.

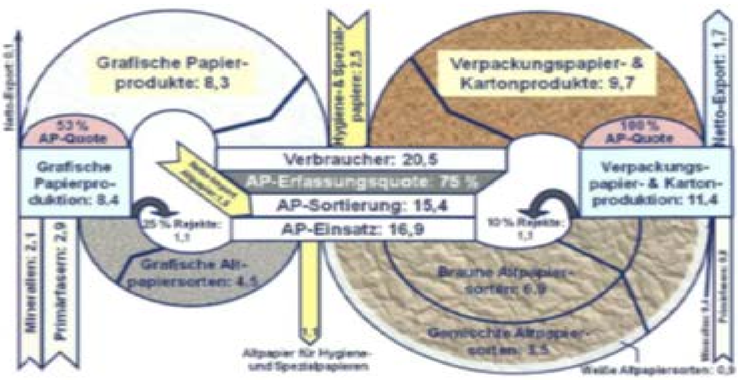

Fig. 3: Fibre cycle Germany 2016 (numbers in million tonnes)

Legend
Netto-Export – net export
AP-Quote – waste paper quota
Grafische Papierproduktion – Graphic paper production
Mineralien – minerals
Primärfasern: primary fibres
Netto-Import – net import
Rejekte – rejects
Grafische Altpapiersorten – Types of graphic waste paper
Verbraucher – consumers
AP-Erfassungsquote – waste paper capture rate
AP-Sortierung – waste paper separation
AP-Einsatz – use of waste paper
Hygiene- & Spezialpapiere: hygiene and specialized papers
Verpackungspapier- & Kartonprodukte – packaging paper and cardboard products
Braune Altpapiersorten – brown waste paper types
Gemischte Altpapiersorten – mixed waste papers
Weiße Altpapiersorten – white old papers
Altpapier für Hygiene- und Spezialpapieren – waste paper for hygiene and specialized papers

One single publication by Koning and Godschall from the 70s is dedicated to the topic of recycling corrugated cardboard carton. For this, first corrugated cardboard is produced laboriously using kraflinter and NSSC fluting (neutral sulphite semi-chemical fluting) and then a corrugated cardboard box is made from this, which is in recycled three time in succession. It is also determined here that the first cycle is the most significant in terms of loss of firmness and a majority of these losses can be compensated for by reactivating grinding. But this publication also does not allow conclusions to be drawn about the behaviour of the raw materials for corrugated board testliner and corrugating medium, which are so important in Germany from the perspective of quantity.

With increasing industrial use of flotation-deinking technology in the 1990s, it was not just industry representatives who wondered how long the recycling of graphic paper products for the production of newsprint from 100% secondary fibre could continue to be successful, if the fibres are increasingly kept in circulation. The Institut für Papierfabrikation (IfP) of the TH Darmstadt studied this question in research project No. 9365 supported by the AiF (*Arbeitsgemeinschaft industrieller Forschungsvereinigungen*. Working Group for Industrial Research Associations) in a pilot project and the experimental results and modellings were discussed in detail summarized by Hunold in a 1997 dissertation. At practically the same time, a team of SCA lab researchers and a Scandinavian industrial consortium on a large scale (large scale pilot study) investigated the same issue. The closed loop investigations of newsprint paper led to practically the same result everywhere with the following key statements:

- Even after 4 or 5 recycling cycles, the quality level of the newsprint paper produced is satisfactory and the papers could be printed well.
- Due to the losses in stock preparation with flotation related to the experiment, after 4 or 5 recycling cycles there was not enough paper available for a further trial cycle, which is why no further trials could be carried out.

In place of these results, the property changes from the IfP experiments, which were extensively presented in the publication by Schabel and Putz and updated with modelling, are reproduced again in Fig. 2. They show that, starting from primary fibre paper consisting of chemical pulp and mechanical pulp, the loss in strength after 5 recycling cycles is only 4% for the breaking length and 17% for the tearing work. The optical parameter degree of whiteness, which is so important for graphic papers, is 18% lower after 5 recycling cycles compared to unprinted primary fibre paper. It is noticeable that the degree of whiteness is reduced from 67% to 60%, i.e. by 11 %, after just the first recycling pass. The subsequent 4 recycling cycles only increase the loss of whiteness by a further 7%.

Model calculations for the average age of the fibre

Whilst the exact number of cycles of fibre material can only be determined in laboratory and pilot tests, real waste paper always contains mixtures of fibres of different and unknown fibre ages. Model calculations can be used to calculate a fibre generation distribution for, e.g., a grade of paper or a country using mass balances and various assumptions. In most cases, this calculated distribution is reduced to the average fibre or generation age. Meinl et al. have further refined such calculations and carried them out for various countries and markets, as well as for paper grade groups and waste paper grades. An average Mean Fibre Age (MFA) of 3.02 and an average Mean Number of Future Uses (MNU) of a further 3.09 cycles were calculated for packaging papers and board and the CEPI economic area, i.e. 6.11 in total. After deducting the first primary fiber paper production, these model calculations for packaging papers and board result in an average fiber utilization of 5.1 cycles. This figure also fits quite w ell with the frequently reported 4 to 7 recycling cycles. Nevertheless, as the average fibre age, based on real quantity

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flow considerations, it says nothing from a technological perspective about how often a fibre can actually be used for paper production.

What development can be expected?

Based on the year 2007 with the highest paper and board production volume in Germany to date totalling 23.3 million tons, a decline of 22.7 % was recorded in the production segment of graphic papers until 2016 and at the same time an increase of 19.0 % was recorded in the area of packaging papers and board. At the same time, the usage rate of waste paper in the production of packaging paper and board is 100%, almost twice as high as in the graphic paper sector (46% - 53%). From this it must be concluded that replenishing fibre in the German paper cycle mainly takes place in the area of graphic papers, for the production of which a large part of the primary fibres used are used in the form of pulp and mechanical pulp. Papers and cardboards for technical and special purposes and hygienic papers are not considered here, as they are rarely used for recycling in paper production after they have been used. Fig. 3 shows the 2016 fibre cycle in Germany, which makes it convincingly clear that – especially in the area of packaging papers and boards – large quantities of recovered paper are now being recycled and the input of fresh fibre is very limited. This means that the supply of good, previously less used fibres will mainly be provided by white (graphic) waste paper grades and graphic paper products in mixed waste paper and that the average fibre generation age in the packaging paper and board sector will continue to increase. This justifies the question of how many recycling cycles a fibre can be subjected to in the packaging paper sector, especially as many paper packaging materials as disposable products are often in direct competition with reusable packaging made of other materials.

Constraints of experimentation

Due to stock preparation losses and the lack of primary fibre input during the closed loop tests for newsprint described above, only a very limited number of recycling cycles could be carried out. In a comparable test with, for example, corrugated base paper, a considerably higher number of recycling cycles could certainly be achieved, since significantly lower losses occur during waste paper processing.

For this reason, a test procedure was first developed in current investigations that allows defibration and sheet formation on a laboratory scale with minimal losses and at the same time exerts a certain mechanical load on the pulp. A (low-consistency) LC pulper was therefore used for defibration, which is a replica of the pulper belonging to the Escher-Wyss laboratory flat cone

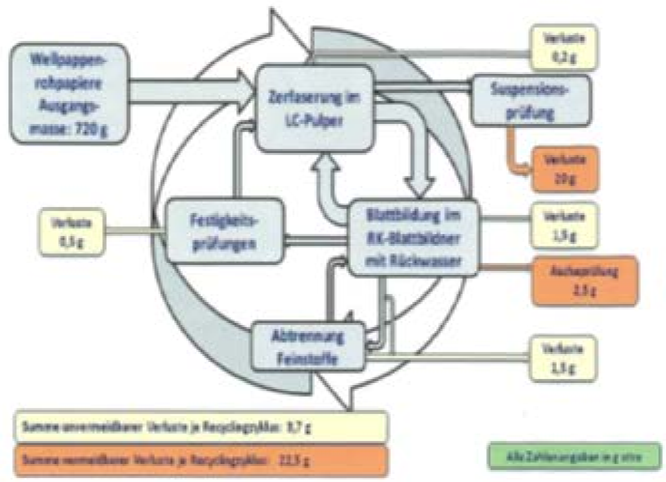

Fig. 4: Closed loop recycling experiment with minimalized loss amounts per cycle

Legend
Wellpappenrohpapiere Ausgangsmasse – corrugated medium initial mass
Verluste – losses
Festigkeitsprüfungen – strength tests
Zerfaserung im LC Pulper – defibration in LC pulper
Blattbildung im RK-Blattbildner mit Rückwasser – sheet formation in sheet creator with recirculated water
Abtrennung Feinstoffe – separation of particulates
Suspensionsprüfung – suspension testing
Ascheprüfung – ash testing
Summe unvermeidbarer Verlust je Recyclingzyklus – sum of unavoidable losses each cycle
Summe vermeidbarer Verlust je Recyclingzyklus – sum of avoidable losses each cycle
Alle Zahlenangaben in g otro – all numbers in g oven-dried

refiner. The laboratory sheet formation was carried out with recirculation water supply in each case. Fig. 4 shows the unavoidable material losses in the individual process steps occurring per recycling cycle, which add up to a total of approx. 3.7 g oven-dried and occur predominantly during the dewatering processes. With the exception of the CMT test strip, all the sample material used for paper testing was returned to the next defibration step after the measurements, so that almost no losses were incurred during the strength tests. In contrast, the suspension tests for determining the Schopper Riegler value or the fibre fractions according to Haindl-McNett, for example, cause considerably higher losses totalling around 22.5 g oven-dried. These losses can be avoided immediately if no test is carried out, which is why it was decided to carry out these measurements only after the 1st, 3rd, 5th and then after five further cycles in each case. Relative to the starting material mass of 720 g oven-dried, the unavoidable losses are 0.5%, while the avoidable losses are 3.1%.
The first comprehensive experiment on closed loop recycling of corrugated base paper as part of the AiF project 19685 N was carried out on PMV with a paper mixture based on the consumption of the paper grade structure in 2015 for the production of corrugated board in Germany. Correspondingly, the following were used:

- 40 % Testliner 3,
- 40 % corrugating medium, and
- 20 % Kraftliner.

Low-consistency pulping was performed at 4% stock consistency at an initial temperature and 60 °C. The defibration time was linearly adjusted to the decreasing volumes of solids during recycling and was a constant 62.5 s/100 g solids, corresponding to 7.5 minutes for the first defibration of 720 g oven-dried and 3.3 minutes for the last defibration of 320 g oven-dried. Since the entire pulper batch had to be processed into laboratory sheets and then defibred again after testing, laboratory sheets of 120 g/m² of area-related mass were produced. After a drying time of 10 minutes each, a residual moisture of approx. 3% was achieved on the laboratory sheets. No primary fibres or minerals were added during the entire closed loop experiments.

Results of the experiments

The figures below show selected results of this first trial run with the corrugated base paper mixture described above over the number of additional recycling cycles based on Johannes Schug's master's thesis. The term ‘additional recycling cycles’ was deliberately chosen in the illustrations, as only this number of recycling cycles was definitely exactly passed through by all fibres in the laboratory test. While the kraftliner fibres, which mainly consist of primary fibres, for the first time complete the cycles mentioned in the laboratory tests, the secondary fibres consisting of testliner and corrugating medium can be assumed to have already undergone an unknown number of recycling cycles prior to these laboratory simulations.
Fig. 5 shows the development of the water retention capacity as a function of the 25 recycling cycles carried out. The graph shows the linear trend line with straight line equation, coefficient of determination R^2 and correlation coefficient r. The linear trend line is shown in the graph. For each investigated test point, the error bar is indicated as the standard deviation for the respective measurement. Over the 25 cycles, the water retention capacity drops from an initial value of about 106% to 92% by a total of 14.5% points due to fibre keratinization. Significant changes in fibre lengths or fibre fraction proportions could not be detected.
The Schopper Riegler value dropped from 40.5 SR by 4.0 SR units between the first and last cycle, parallel to the ash content (525°C) in the laboratory sheet, which fell from 7.9% to 5.8%.
The error bars for determining the apparent density (Fig. 6) are larger compared to the water retention capacity. Nevertheless, there is a clear trend towards less rigid paper. The apparent density drops by 0.025 g/cm³ between the first and last recycling

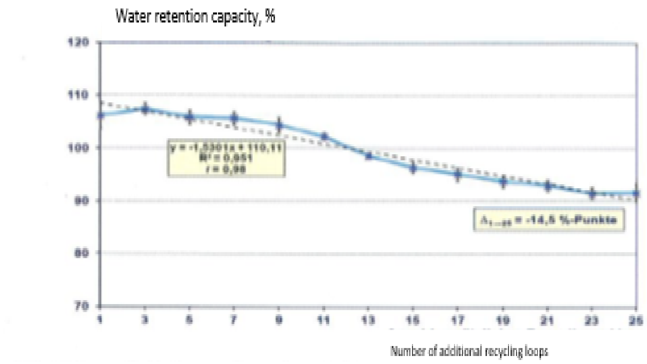

Fig. 5: Water retention capacity of a corrugated medium blend depending on recycling cycle

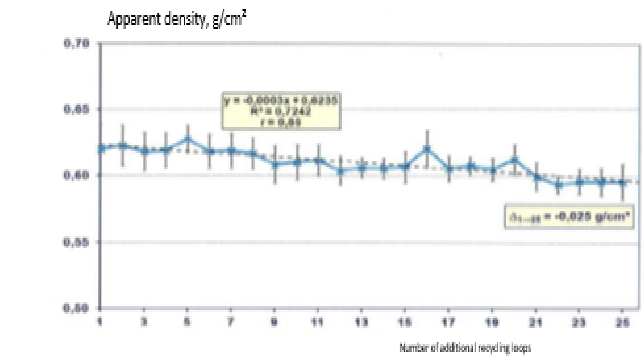

Fig. 6: Apparent density of lab sheets (120 g/m²) from corrugated medium blend depending on recycling cycles

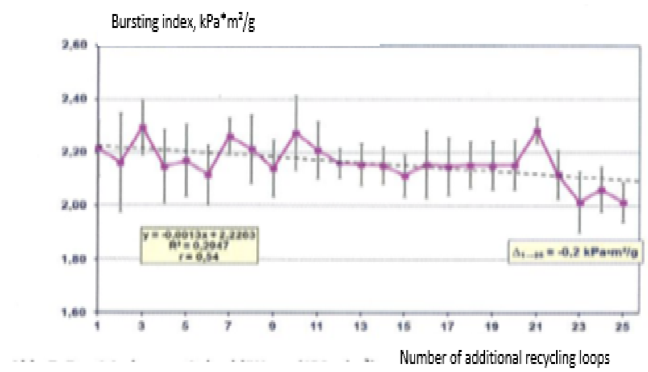

Fig. 7: Burst index of lab sheets (120 g/m²) from corrugated medium blend depending on recycling cycles

cycle of 0.620 g/cm³, which corresponds to a decrease of about 4 % of the initial value.

Fig. 7 shows the development of burst strength by basis weight as a burst index with error bars per test point and trend line over the recycling cycles. Since all strength parameters of the laboratory sheets were determined after each recycling cycle, 25 measured values are available. Although the error bar is relatively large and the correlation coefficient relatively low, a clear trend over the recycling cycles can be seen. Overall, the burst index of 2.2 kPa-m²/g drops by 9% in the first cycle to the last cycle, which corresponds to an absolute reduction of 0.2 kPa-m²/g.

Fig. 8 shows all the strength parameters measured on the laboratory sheets (breaking length, tear propagation energy index (WRA index), burst index, SCT, RCT, CMT) in relative terms, i.e. they are expressed as a percentage of the respective measured value of the first cycle. In order to keep the graph clearer, the display of error bars and trend lines with linear equation, coefficient of determination and correlation coefficient was omitted. The percentage losses between 1st and 25th cycle is between 5.1% and 11.6% and are particularly low for the parameters tear length, CMT and RCT and highest for SCT and WRA index. Although the individual values of a parameter fluctuate from one cycle to the next and sometimes increase, the trend over the 25 cycles is clear, as Fig. 9 shows. It shows the trend lines for the parameters shown above with the corresponding correlation coefficient, which lies between 0.54 and 0.81. The trend lines show the trend over the 25 cycles. The trend lines illustrate the range in which the decrease in strength lies over the additional 25 recycling cycles for the corrugated base paper blend used, with 20% primary and 80% secondary fibre content.

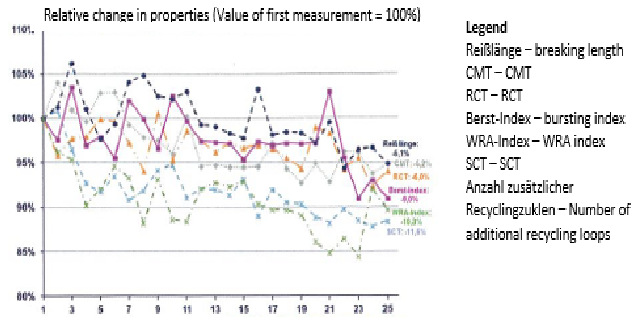

Fig 8.: Relative change in lab sheet strength properties (120 g/m² of a corrugated paper blend depending on recycling loops

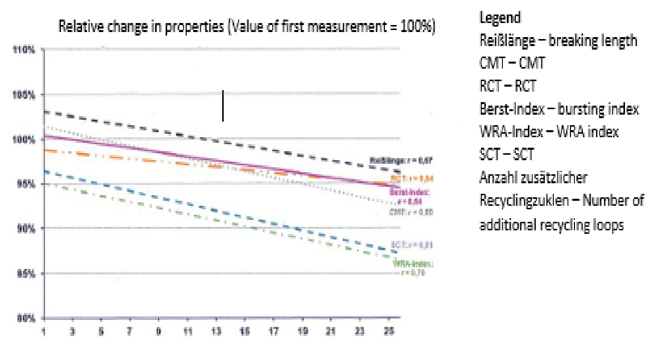

Fig 9.: Trends in relative change in lab sheet strength properties (120 g/m² of a corrugated paper blend depending on recycling loops

Perspective

Within the context of the AiF project 19685 N, further investigations will be carried out on the closed loop recycling of corrugated base paper and of raw materials for the production of corrugated base paper. In particular, the special features of corrugated base paper production based on waste paper with a targeted application of starch in the mass or in the glue and film press to increase strength will be discussed. A further focus of the investigation is the possible effects of corrugated board production with the mechanical and thermal stress during corrugation and drying of the starch adhesives used. Before the project is completed at the end of 2019, a pilot test on the PMV test paper machine will round off the results.

Conclusions

The simplistic statement that paper fibres can be recycled 4 to 7 times and are then too weak to produce paper again has been refuted. The models known from the literature refer to mass balances and do not provide any information on how many recycling cycles a fibre can actually survive without significant damage. If paper is not produced from primary fibres, a mixture of fibre generations of unknown age must always be recycled. Therefore, tests with a defined number of recycling cycles can only be carried out on a laboratory or pilot scale. Older literature references show that for various primary fibre materials with up to 12 recycling cycles, the greatest changes occur during the first 2 - 4 cycles. First attempts at multiple recycling were made with a corrugated base paper mixture that was oriented to the consumption of the German corrugated board industry and contained 80% secondary fibre paper. A total of 25 (additional) recycling cycles with defibration were carried out in a low-consistency laboratory pulper and recirculated water sheet formation without any addition of fresh fibres. The results of the suspension test in closed loop recycling indicate a slight reduction of the values for water retention, Schopper Riegler and ash content over the 25 cycles. In the closed loop tests in the laboratory, only minor losses in the range of 5 % to 12 % were observed over the 25 recycling cycles for all relevant strength parameters. The initial reason for this is the low primary fiber paper content of only 20% in the overall blend, since all other fibre components have already undergone the first recycling cycles with the particularly high adverse effects.

However, it should not be forgotten in all of these model or pilot trials that the challenge for paper mills when using waste paper as a raw material for paper production is primarily the separation of impurities that are foreign to paper and by-products of paper production. The removal of these materials is never 100% successful and thus leads to a deterioration of quality through closed loop recycling. Here it would be desirable for manufacturers of paper products to focus more on questions of recyclability when designing such products and to pursue "design to recycling". However, such questions could not be considered in the laboratory and pilot tests presented here.

Acknowledgements

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