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Extending the limits of paper recycling: improvements along the paper value chain

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Abstract

Aim of study: The purpose of this study is to analyze how paper recycling activities in Europe can be extended through different improvements along the paper value chain. The importance of this study lies in the identification of the present barriers in paper recycling and how they can be overcome.

Area of study: Europe.

Material and methods: All the main stages along the paper value chain have been analyzed for possible improvements: collection of recovered paper (availability and quality), sorting of recovered paper, paper production, and printing and converting activities.

Main results: To increase paper recycling in Europe the following improvements are necessary. First, it is mandatory to increase the availability of recovered paper through more efficient collection systems (avoiding the use of commingled collection systems) and limiting the competition with energy purposes and the exports. Second, it is necessary to extend sorting activities, which can be achieved by reducing sorting costs by the use of automatized sorting systems. Third, there is a need to increase the recyclability of paper products by the commitment of printing and converting industries to use recycling-friendly printing inks and adhesives. Finally, environmental awareness of the citizens is still an important driver for increasing recycling activities, affecting not only recovery but to all the stages along the paper recycling chain.

Research highlights: Although the recycling rate in Europe is already very high (68.9%), there is still room to further extend paper recycling activities through different improvements along the paper value chain.

Key words: paper recycling; sustainability; paper value chain; recovered paper; environmental awareness.

Introduction

Papermaking is one of the oldest and leading recycling industries. The traditional driver to increase paper recycling has been economic, but at present, environmental and ecological concerns are also important. Thus, this sector has become an example of sustainability. Over the past decades, the recovery and utilization of recovered paper in the paper and board industry has increased throughout the world, *i.e.* recovered paper demand increased from around 90 million tons in 1990 to around 220 million tons in 2011 (RISI, 2012). Today, recovered paper accounts for around 50% of total papermaking fibres used at worldwide level.

Europe is leading paper recycling, with a 68.9% recycling rate (recovered paper utilization plus net trade, compared to paper and board consumption) (2010 data). This means around 49 million tons of recovered paper utilized in the paper and board industry. Voluntary commitments of the paper recycling chain, reflected in the different European Declarations on Paper Recycling signed since 2000, have helped to achieve ambitious targets on paper recycling, making paper the most recycled product and Europe the global champion in paper recycling. On the other hand, the commitment of environmental transparency trough sustainability reports has been also an important step towards. In fact, European paper industry was the first European industry sector launching these reports in 2003 (CEPI, 2003a).

Fig. 1 shows a comparison of recycling rates versus utilization rates (percentage of recovered paper utilisation compared to the total paper production) in the different European countries. The size of the bubbles corresponds to the pulp and paper utilisation in the country. The average utilization rate is 50.8%, varying largely around in Europe from 5 to 105% (2010 data).

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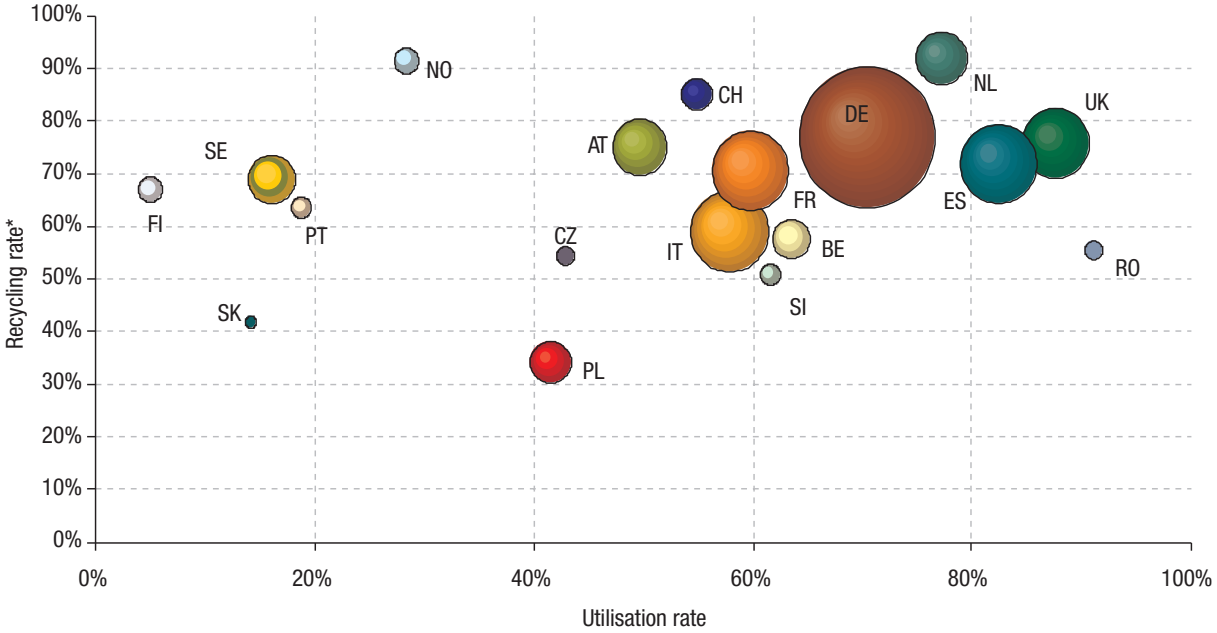

Figure 1. Recovered paper recycling rate and utilisation rate and utilisation in CEPI countries in 2010. *Note:* Bubble size is proportional to recovered paper utilisation. *Source:* CEPI (2011).

The lowest utilization rates are in the Nordic countries, with a higher production of paper and board from virgin fibre due to their vast forest resources and strong wood pulp industry, *i.e.* Finland (4.9%), Sweden (16.1%), or Norway (28.3%). The highest utilization rates are in Hungary (105.3%), Romania (91.0%), Spain (82.4%), United Kingdom (75.9%) and The Netherlands (77.2%), where the domestic industries are almost based only on recovered paper as fibrous raw material. Low utilization rates in Nordic countries and high utilization rates in the other European countries complement each other perfectly, making paper production a sustainable global process, as an injection of fresh fibres is always necessary to keep the cycle running.

In addition, it is important to notice that an increasing part of the recovered paper collected in Europe is utilized elsewhere in the world. In the last six years, exports of recovered paper from Europe to other regions increased from 5.59 million tons in 2004 (net trade of 4.77 million tons) to 9.38 million tons in 2008 (net trade of 8.16 million tons), being Asia the destiny of more than 95% of the exportations.

The utilization rates by grades are very different, depending on the final paper quality and price, varying from 10% to more than 90%, depending on the grade (Fig. 2). Utilisation in packaging papers is, on average, 75.3%: 93.8% in case materials and 42-52% in other packaging paper grades such as carton board, wrappings and others. In newsprint, utilisation rate is 92.8%, while is only 10.6% for other graphic papers. In household and sanitary, the utilisation rate is 50.2%, and 38.7% in other papers. Clearly, the highest potential for an increase in the use of recovered paper is in other graphic grades but special attention must be given to aspects such as the removability of adhesives and deinkability, *i.e.* flexo inks or digital printing techniques, limits its use in these grades. The main uses of recovered paper in Europe in 2010 were: 63.7% for packaging paper production, 26.0% for graphic papers (18.6% for newsprint and 7.4% for other graphic papers), 6.9% for household and sanitary, and finally, 3.4% for other papers.

Paper production cannot be based only on recovered paper, as it neither be efficiently used in all paper grades, nor can be used indefinitely. Paper recycling needs to continuously incorporate a certain amount of fresh fibres for three main reasons: a) strength: cellulose fibre deteriorates each time it is recycled; b) quality: some paper and board grades make little or no use of recovered fibre because certain properties are better and more economically provided by virgin pulp; c) availability: some paper products are not sent for recycling (books, documents, photographs, etc.) and in other cases, paper products are deteriorated or are destroyed when used (sanitary paper, cigarette paper,

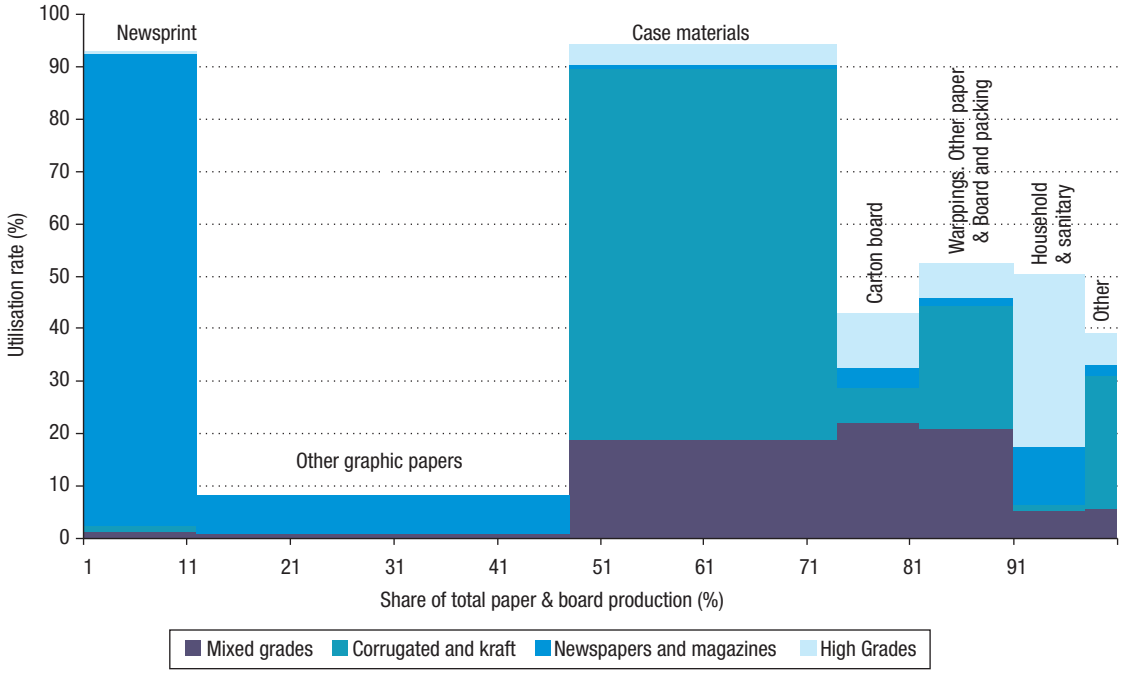

Figure 2. Recovered paper utilisation by sector in CEPI countries in 2010. *Source:* CEPI (2011).

etc.). It is estimated that around a 19% of the paper used is not collectable or recyclable (CEPI, 2003b). Additionally, it is not always economically viable or environmentally sound to collect every piece of paper due to the heavy transportation that would be required.

Although not all products are suitable to be manufactured from recycled fibre, and the system always requires an injection of fresh fibre, there is still room to continue extending paper recycling despite the recycling rates are already very high in Europe. However, certain factors have a limiting influence on the possibility of an extended use of recovered paper, such as the availability of recovered paper, the quality of the recovered paper, the poor sorting activities, the price of recovered paper, the recyclability of the paper products, the acceptance/demand of recovered paper-containing products by the consumers, etc., as it was studied in COST Action E48 (Levlin *et al.*, 2010). The future of paper recycling will be a consequence of the importance of social, economic, technical, environmental and legislative issues on the different paper recycling chain stages such as collection, sorting, production technologies, as well as printing and converting (Blanco *et al.*, 2004; Miranda *et al.*, 2010). The objective of this paper is to identify the possibilities to extend the limits of paper recycling along the paper processing chain.

Potential improvements along the paper value chain

Collection of recovered paper: availability and quality

The collection of used paper and board is the first step in the recycling process. The increase of the availability of recovered paper has been considered as the most important area to extend the limits of paper recycling (Miranda *et al.*, 2010). As it has been previously commented, the demand for recovered paper has increased much in the last decades. At European level, utilisation of recovered paper has doubled in the last two decades, from 25.70 million tons in 1991 to 48.97 million tons in 2010 (CEPI, 2011).

The collection of recovered paper is already very high in Europe. In 2010, the collection rate (ratio between the recovered paper collected and the paper consumption, expressed as percentage) was 66.8%, which means 57.14 million tons of recovered paper was collected for paper recycling. Due to intensified collection in each country, the average collection rate has increased sharply during the last years, from 41% in 1991 to 56% in 2002, and 67% in 2010 (CEPI, 2011). However, there are important differences between the countries: some of them are very close to

the limit for the collection of recovered paper, *e.g.* Germany, The Netherlands or Norway, with collection rates between 75% and 90%, but others are still far away, *e.g.* Poland has a collection rate lower than 40%. Consequently, there is still an important potential to recover more used paper in Europe, mainly in the Eastern countries, where the collection systems are less developed. In addition, there is an increasing amount of recovered paper being exported to Asia. In 2010, the consumption of recovered paper by the domestic industry was around 48.97 million tons, around 85% of total recovered paper collected in Europe.

However, one of the major threats of an extended collection is its influence on the quality of the recovered paper. The reason is the fact that first easy-to-collect and high quality sources of used paper are exploited, while by increased demand, other sources with a lower quality and more disperse generation are exploited (recovered paper coming from households) (Faul, 2010; Miranda *et al.*, 2011). At European level, a rough estimation of the different sources of recovered paper indicates that 50% of used paper and board is collected from industry and trade, 40% from households and 10% from offices (CEPI, 2006), although these percentages can differ greatly between countries.

Considering the theoretical maximum recovery rate of 81%, this means that the recovery rate of 66.8% obtained in 2010 in Europe is equivalent to a paper collection efficiency of about 82.5%. However, this maximum recovery can not be considered as an absolute value and depends on many factors such as the paper consumption of non-recyclable products (mainly hygiene papers), the volume of shavings and cuttings from printing and converting industries (internally recycled), or the packaging paper coming with the trade of goods. For example, packaging paper coming with the goods imported from China and Far East can represent at global level around 10-15 million tons (Miranda *et al.*, 2010). This is the reason why some countries have higher collection rates than those theoretically possible, *i.e.* The Netherlands (91.6%) or Norway (91.7%) (CEPI, 2011).

The type of collection system is important, especially in terms on quality of the recovered paper, but other issues such as renewable energy policy, trade of recovered paper and environmental consciousness of the citizens, are also important on the availability of recovered paper for recycling.

Type of collection system: source-separated versus *commingled collection system*

The collection strategies are important for increasing paper recovery, but they are even more important regarding the quality of recovered paper. In this sense, the method of collecting recovered paper has a direct impact on the composition of recovered paper and determines the further steps of recovered paper processing (sorting processes) (Faul, 2010). The collection systems vary depending on the municipality, region or country considered, and of course are a function of the source regarded. However, there is clear distinction between source-separated and commingled collection systems.

In commingled collection systems, all recyclable materials are collected together in a single container, and include a mix of paper and board, glass bottles, cans, plastics, etc. Although the materials are then sorted in a materials recovery facility (MRF), the recovered paper is highly contaminated, *e.g.* total unusable materials can vary between 5% and 20%, which limits the possibility to be recycled, especially for graphic paper production (Emerson, 2004; Miranda *et al.*, 2011; Miranda *et al.*, 2013). Commingled collection systems are sometimes the favourites of the municipalities and the waste management companies because they reduce collection costs while increasing recovery rates (Emerson, 2004; Faul, 2005). However, from a purely paper reprocessing point of view, it is doubtful whether the benefits of cheaper collection of commingled recyclables outweighs the extra costs of higher processing costs (sorting) and the removal of more contaminants during the process (Miranda *et al.,* 2013). In fact, the shift from source-separated to commingled collections can be as detrimental that it could even justify the change of raw material to virgin fibres (Sacia and Simmons, 2006). Commingled collection systems are gaining more and more importance, especially in the United States and United Kingdom, but they are also spreading to other European countries such as France (Faul, 2005). For extending the limits of paper recycling, source-separated collection systems are mandatory.

Waste policy

The new Waste Framework Directive (2008/98/CE) of the European Union (OJ, 2008) will have an important effect on increasing the availability and

quality of recovered paper. Two important achievements have been obtained through this Directive. First, the threat of spreading commingled collection systems has been minimized as the separate collection for paper, metal, plastic and glass will become mandatory in all member states by 2015. Second, a mechanism for specific waste streams to cease to be waste has been introduced ("end-of-waste" criteria). Due to the potential benefits which can be expected by the recovered paper ceasing to be considered as waste (legal, economic, etc.), further efforts are expected along the recovered paper value chain to reduce contamination of recovered paper to meet the quality requirements included in this end-of-waste criteria (1.5% unusable material content) (Villanueva and Eder, 2011).

Renewable energy policy

In recent years, it has been demonstrated that energy market may disturb the availability of recovered paper for papermaking and increase its price. Due to its renewable origin, recovered paper can be considered as biomass and therefore, a renewable energy resource. Although incineration of used paper generates renewable energy, it is more efficient and sustainable to burn used fibres only when they can no longer be recycled (the fibres have lost their papermaking abilities) (ERPC, 2011a).

In this sense, renewable energy policies are a threat if the waste hierarchy, whereby material recycling is a priority over energy recovery, is not really implemented. Subsidies for renewable energy production allocated in the framework of feed-in tariffs or green certificates must not favour energy recovery from used paper above material recycling. The new Waste Directive has given recycling a clear priority over incineration and this threat has been significantly minimized. However, in this Directive, composting is also considered as material recycling. As once paper is composted it disappears from the paper recycling loop, this option is not the preferred by papermakers; and it should only be applied to materials that are not suitable for recycling (*e.g.* paper soiled with food) (Monte *et al.*, 2009).

Trade of recovered paper

The net trade of paper for recycling was 8.4 million tonnes in 2010, mainly due to exports by Asian buyers, particularly China. In 2010, China imported 24.4 million tonnes of paper for recycling, most of it from Europe and North America. Unbalanced imports of paper for recycling by companies outside Europe could have a negative impact on paper recycling in Europe. The Communication from the Commission on Raw Materials (2011) highlights the importance of the enforcement of the waste shipment regulation and further actions to ensure environmentally-sound management in recycling facilities. In this sense, a recent study published by ITENE (2012), estimated that transport emissions contribute significantly to the overall environmental impact of recycling. The recycling of paper and board domestically would achieve a more positive balance, specifically equivalent CO_2 emissions saving would increase by 30%, if, for example, the pollution generated in the transportation of recovered paper from Spain to China would be considered. Whatever the case, the increase in the collection of paper must be higher than the increase in the net trade of recovered paper for not disturbing raw material availability for domestic industries.

Environmental awareness

Based on an European survey, environmental consciousness of the citizens is still one of the main driving forces for obtaining higher volume and higher quality recovered papers (Miranda and Blanco, 2010). As other recovered paper sources (mainly industrial and trade) have to a great extent, already been tapped, the future potential for recovered collection clearly lies in households. Without efforts on source segregation and separate collection from households, which are major prerequisites for sustainable recycling, it would be very difficult to extend the use of recovered paper as a raw material in the papermaking industry. Awareness campaigns will still be useful tools to achieve this aim.

Sorting of recovered paper and board in Europe

As it was commented before, an extended paper recovery is always detrimental to its quality. At the same time, papermakers are urged to gradually improve the quality of their final products no matter the quality of the raw material. Besides, the main potential for an extended use of recovered paper is in graphic

papers, where the quality requirements for the final product have always been high and where they need to respond to the new challenges set by rapid technological developments in printing and converting techniques. For all these reasons, an improved and extended sorting of the recovered paper is of great importance for extending recycling of paper in Europe. Practically, the method and intensity of sorting determine the quality (the type and content of different contaminants) of the recovered paper supplied to the paper mill (Bobu *et al.*, 2010).

Sorting can be carried out at different locations, *e.g.* sorting at source (households), sorting at industry/offices, at collection centres or sorting plants, and at paper mills. No matter where it is done, the main advantages of sorting are: a) the reduction of the content of unwanted components in recovered paper and an increased homogeneity of the raw material and b) the provision of tailor made recovered paper grades for the best possible re-use in paper and board products (Miranda *et al.*, 2010).

Basically, three main sorting strategies are in use: manual, semi-automatic and automatic. Despite the new technological developments, sorting of recovered paper is still mainly manual, requiring only an inclined conveyor and a speed-adjustable sorting belt. This process is very intensive in labour and, consequently, its cost is high.

At present, costs are still the main obstacle for an extended sorting of the recovered paper, but automatic sorting systems are promising alternatives for the future (Bobu *et al.*, 2010; Sánchez, 2009). These plants are based mainly on mechanical screening, but new optical technologies are being incorporated (Vis/IR); nevertheless, they still have in common a final manual sorting step at the end of the process. Although some problems remain to be solved, such as the automation generates grades that do not correspond exactly to the EN 643 list (Wagner *et al.*, 2006), the use of new technologies for the automatization of the sorting process can effectively reduce the sorting costs. Nevertheless, the extent of investment for these automatic systems is high. One of the most modern sorting plants in Europe, built by Carpa by the end of 2007 in Madrid (Spain) to sort the recovered paper coming from selective collection from households, required an investment of around 8 million Euros. This plant is based on mechanical sorting, optical sorting (IR) and manual sorting (in the final stage), and its throughput is 200,000 tons per year.

Despite sorting itself, dry-sorting costs and paper quality depend largely upon the degree of mixing in the collecting systems. Regardless of the investments made in new installations for extended sorting activities in Europe and the research carried out on sensor-based sorting technologies, *e.g.* the FP7 project "Recovered paper sorting with innovative technologies" (SORT IT) (2008-2011) (Bobu *et al.*, 2010; Levlin *et al.*, 2010), it is necessary to emphasize that sorting at source and separate collection are always the best ways to ensure a good recovered quality, thus allowing an extended use of this raw material by the paper and board industry. This can be promoted by awareness campaigns.

Paper production

Further improvements in paper production technologies can also contribute to extend the limits of paper recycling. Optimized pulp preparation plants with a high degree of sophistication can treat lower quality sources without affecting the quality of the final product. The key for an optimum efficiency of the plant is the efficient removal of contaminants at the earliest process stages, at the minimum cost and maintaining a high yield. Although there is a great variety of contaminants coming with recovered paper, inks and adhesives are probably the two most important. High levels of stickies or inks in the pulp can make impossible to achieve the final product requirements. At the same time, processing costs should kept at minimum, obtaining higher yields, lower rejects in the process, and also considering environmental and sustainability criteria.

Deinking

Deinking is of major importance in the production of graphic papers due to the high demand of optical properties of the finished products. To be able to meet those requirements, improved deinkability of printed paper products has become essential and one of the most important prerequisites for increasing recycling rates, as most of the potential for an extended used of recovered paper lies in these graphic papers (Faul and Putz, 2009). In addition, it is also becoming of interest in packaging grades, due to the growing tendency to print certain products such as cartonboard.

The efficiency of the deinking treatment depends on many factors, *e.g.* quality of the recovered paper, the type of printing process and properties of the printing inks. Moreover the ageing process and climatic conditions during the life cycle of the print products, mainly in the case of offset prints, influence the result. However, the printing process and the printing inks are the key factors influencing the deinkability of recovered paper.

Deinking by flotation is the predominant technology used in Europe, Asia and North America. Supported by surface active substances, printing ink particles gather on the surface of air bubbles and are removed from the pulp. This process works at an optimum with printing ink particles sized between 20 μm and 100 μm. An efficient flotation process needs additional certain characteristics of printing inks: they have to be hydrophobic and need to be in a certain particle size range in order to be floatable (Faul, 2010). There are a lot of improvements currently under study, for a great variety of non-conventional inks and printing techniques, including modification of deinking chemicals (*e.g.* enzymatic deinking), stock preparation, pulping, and the flotation process (Delozier and Deng, 2003; Bobu and Ciolacu, 2008; Shemi and Hsieh, 2010; Ibarra *et al.*, 2012). However, new inks and printing techniques are still an unresolved problem. As occurs with adhesives, there is a need to focus on the origin of the problem by developing eco-friendly inks and printing techniques.

Stickies removal

Most products made of paper and board are put together with the help of adhesives to form complex finished products. A low sticky potential from adhesive applications is a common requirement for both packaging and graphic paper products (Levlin *et al.*, 2010). On the other hand, printers and publishers also introduce adhesives through their use of ink binders, address labels, and book bindings. In addition, container manufacturers may use wax or hot melt coatings to impart water impermeability to boxes. Stickies coming from adhesive applications affect both the process efficiency because of the formation of deposits, the production of breaks, or the reduction of the dry section efficiency due to felt clogging, and the quality of the final product because of the presence of spots, holes, and other defects (Delagoutte, 2005; Blanco *et al.*, 2002).

Stickies control approaches are based on limiting the stickies entering to the process, the ideal situation being the development of eco-friendly adhesives, and by controlling stickies in the process. In this case, stickies can be controlled by (Blanco *et al.*, 2002; Hubbe *et al.*, 2006): a) preventing the release of stickies from the raw material (*e.g.* controlling pulping and dispersing time, pH, and consistency), b) removing stickies during stock preparation (*e.g.* screening, cleaning, flotation), c) minimizing the negative effects on paper appearance (*e.g.* dispersion), and d) preventing deposit formation in the paper machine (*e.g.* detackifiers, talc, fixatives, barrier chemicals).

Although lot of efforts have been carried out during the last decades, stickies problems have been a constant in recycling operations and are expected to be even worse in the future. The reason is that the use of adhesives in paper products is continuously being increasing while the efficiency of the deinking lines to remove stickies has remained practically constant since 1996 (Hanecker and Faul, 2007; Hamann, 2009). Again, there is a need to focus the solution on the origin of the problem by developing eco-friendly adhesives.

Processing costs: energy, waste rejects management, price of recovered paper, etc.

Processing costs should be reduced at minimum for a sustainable paper production based on recovered paper to continue being competitive *versus* virgin fibre. However, low quality recovered paper and other market conditions such as the price for energy or recovered paper, increase constantly the processing costs.

One of the most important contributions on processing costs related to higher recycling rates are the costs related to low quality recovered paper. In a simplified approach, these costs are related to three factors (Monte *et al.*, 2009; Miranda *et al.,* 2011): (a) the prices of recovered paper (if there are more contaminants accompanying the paper, there are lower fibres per ton of recovered paper), (b) the costs of waste disposal (landfill taxes) and (c) the solids content of the waste to be disposed (which implies more tons to be landfilled). The mills are facing increasing costs for these increased levels of contaminants (unusable material and non-paper components) which will be even more important in the future due to the higher landfill taxes and the price of recovered paper. These high levels of contaminants also imply brightness loss, increased stickies content, etc., in the final pulp.

Printing & converting

As it has been already pointed out, printing and converting industries are of great importance regarding the recyclability of the paper and board. Adhesives and printing inks used in their operations continue to be a major problem and a lot of ongoing research projects within Europe are focused in these problems (Faul and Putz, 2009; Levlin *et al.*, 2010). Eco-design of paper and board products, which directly translates into their recyclability, is a key issue for producing high quality recycled pulp and, consequently, to extend the use of recovered paper.The European Recovered Paper Council (ERPC), through the Declaration on Paper Recycling, is promoting the importance of the eco-design of paper products along the whole paper and paper recycling value chain. The International Association of the Deinking Industry (INGEDE) and some partnerships among the added value chain have also carried out a lot of efforts to improve the awareness of the recycling problems caused by their printing and converting processes (ERPC, 2011a; Levlin *et al*., 2010).

High recycling rates require that paper products should be manufactured considering their recyclability to keep the recycling cycle running. In fact, in almost every area, possibilities are already available to improve the recyclability significantly (Putz, 2007).

Two important issues to deal with the problem of recyclability are the establishment of recyclability criteria accepted by the paper value chain, and an effective communication between papermakers and printing and converting industries.

Standardized methods to measure recyclability

Tools to assess the recyclability of printed paper products have been already developed, covering the two major topics: removability of adhesives and deinkability. As occurs with other factors affecting the quality of the recovered paper, and especially with stickies, one of the main problems that hold back the development of adhesive less detrimental to paper recycling is certainly the difficulty to evaluate the real behavior of a given adhesive product in a recycling line (Delagoutte, 2005; ERPC, 2011b). In this sense, the standardized methods widely accepted along the paper value chain are key and the first stage to find an agreement among the members of the paper recycling chain.

During the latest years, great efforts have been carried out by the European Recovered Paper Council (ERPC) together with INGEDE and its research partners, and finally two schemes for measuring deinkability and removability of adhesive have been adopted to promote the eco-design of products.

First, in 2009, the ERPC adopted the deinkability scorecard (ERPC, 2009). This scheme is designed to allow printers, publishers and other members of the paper value chain to identify which types of printed paper products are sufficiently "deinkable" with currently available technologies. Five parameters — luminosity, colour, cleanliness, ink elimination and filtrate darkening— are considered in a widely accepted standardised test, Method 11, developed by INGEDE (Faul and Putz, 2009). Following laboratory tests the results of the scorecard's five parameters are weighted according to their importance and displayed either numerically or graphically in a traffic light colour scheme. There are four categories of results – good, fair, poor and not suitable for deinking.

The removability of adhesive applications has been adopted after, in 2011. It can be assessed by looking at its removal score, which can range from –20 to + 100 (ERPC, 2011b). In this regard, the removability depends not only on the composition of the adhesive but also on the type of application, such as the shape of the application and the thickness of the layer. The procedure is based on INGEDE Method 12 and it is applicable to all kinds of printed paper products containing any adhesive applications.

Printing and converting awareness on recyclability of paper products-communication

Although some efforts have been carried out, as the establishment of standardized tests to measure recyclability, the impacts of printing and converting techniques on product recyclability have been also looked upon. All across Europe, the awareness of the problems and constraints of the paper recyclers, in the domain of printing and converting industries, is poor to non-existent.

There have been and still are taken some efforts to improve communication among sectors, however, the higher costs have been argued as the main reason for not using the more expensive eco-friendly additives. In this sense, there seem to be two promising ways to increase motivation in the industry sector to produce

better recyclable products, namely by paying subsidies and reinforcing legislation and regulations.The development of an effective communication basis between paper recycling industry and printing and converting industries has been and still will be a hot topic. Corresponding efforts have been made —with little to no success— (Miranda *et al.*, 2010; Levlin *et al.*, 2010). However, the paper industry should not stop to undertake any reasonable effort to intensify the dialogue with their clients – and vice versa. Consumer interest in environmental issues can also help persuade firms to be environmentally friendly and to develop innovative green products by the choices they make.

Printing techniques and deinkability

As it has previously commented, deinkability of recovered paper is of major importance in the production of graphic papers due to the high demand of optical properties of the finished products and also becoming of interest in packaging grades. A good deinkability has become one of the most important prerequisites for increasing recycling rates, as most of the potential for an extended used of recovered paper lies in these graphic papers (Faul and Putz, 2009). In addition, it is also becoming of interest in packaging grades due to the growing tendency to print certain packaging grades such as cartonboard. Although the efficiency of the deinking treatment depends on many factors, printing process and printing inks are key factors influencing the deinkability of recovered paper.

Two of the most common printing methods are offset and rotogravure printing, which can be deinked with conventional techniques as the inks are hydrophobic and fragment into a proper particle size during repulping (Faul and Putz, 2009). However, as a result of the developments in printing process and paper technology, various new inks and paper grades are entering the recycling chain, which may need different removal techniques. Conventional deinking technology is ineffective in deinking recovered printed paper that includes new type of printing processes and ink, such as flexographic newspaper printing, digital printing with liquid toners and inkjet printing and UV cured inks and varnishes (Bobu and Ciolacu, 2008; Levlin *et al.*, 2010).

Utilisation of water-based flexographic printing is getting more common in some geographic regions for newspapers. The presence of newspapers printed using flexographic process, even in small quantities amongst newspapers and magazines printed using offset and rotogravure processes can render them unusable for recycling. Due to the poor deinkability of flexo inks, mills keep flexo-printed paper out of the system avoiding recovered paper from regions in the UK or Italy, where flexo-printed newspapers are dominant, or limit to a low value, determined empirically in several mills to be 5-10% (White, 2007; Faul, 2010; Shemi and Hsieh, 2010).

Additionally, digital or electronic printing is of increasing utilization for fine papers, *e.g.* xerographic or laser printing and ink-jet printing. In the past —and still to some extent today— digital printing has mainly been used for low volumes, because there is less initial setup, it is useful for rapid prototyping, and cost effective for small print runs. As the technology and quality has improved, so have the opportunities. Today, digital printing processes are about to supplement offset printing in many areas and open up new business opportunities, involving also larger print runs. Printing on demand systems for short run books of varying page quantities and binding techniques, or variable data printing for personalized printing, are two examples. But some digital printing processes have serious disadvantages in terms of deinkability in the paper mill such as liquid toners for xerographic and laser printing, and inkjet inks for inkjet printing. Inkjet and liquid toner prints represent real threats for deinking mill. Much work is still needed to ensure that these two printing technologies produce deinkable prints (Faul and Putz, 2009).

UV printing is different from conventional printing in many ways. In this case, the ink dries through a completely different process. The key driver for the adoption of this technology was the reduction in volatile organic compounds (VOCs), resulting from the solvents removal. Another significant benefit of UV technology is the lowering of operating costs. This is achieved through increased productivity, energy savings and the elimination of solvent recovery costs. UV technology is used in screen printing, some inkjet inks, CD-ROMs printing, etc.

The research and development activities in this field led to some improvements but these have not reached a commercial status. The first printing inks with somewhat improved deinkability are presently being tested. High quality recycling papers, however, cannot be produced (Faul, 2010). A lot of research is currently being done, mainly focused on inks and deinking

processes. Development and design of print products are dynamic. Materials and processes, too, are subject to technical innovations. Therefore it is necessary that all parties involved evaluate their products recyclability. This research is of great importance, because if deinking of papers printed with non eco-friendly inks could be recycled, the present limits of paper recycling could be extended. The paper mills, together with manufacturers of printing inks, their associations and publishers, are continuously investigating the deinkability of current print products. Efforts are also being made in co-operation with manufacturers of printing inks to replace inks that have a poor deinkability with inks that are better in terms of recycling. Good examples of this collaboration are the works carried out within COST Action E46 "Improvements in the understanding and use of deinking technology" or the Digital Print Deinking Alliance.

Converting techniques and sticky potential

A low sticky potential from adhesive applications used in converting operations is a common requirement for both packaging and graphic paper products. As it has been commented before, stickies problems have been a constant in recycling operations during the last decades but they are expected to be even worse in the future. The reason is that first, there is a continuous higher use of adhesives in paper products, and consequently, there will be a higher income of adhesives with the raw materials. L. Hamann (2009), for example, estimated adhesive amount in recovered paper has grown about 4% per year between 1997 and 2006 in Germany. Second, there are other trends in papermaking contributing to worse the problems related to stickies, such as: the basis weight reduction, the paper machine speed increase, the increase in the concentration of microstickies and dissolved and colloidal material due to the closure of water circuits, etc. (Blanco *et al.*, 2002; Delagoutte, 2005).

One of the most ambitious studies related to characterize the quality of graphic recovered paper and deinked pulp have been carried out by PTS Munich, financed by the INGEDE, during the period 1996-2005 (Hanecker and Faul, 2007). This study has demonstrated that the increase income of adhesives with recovered paper, together with the fact that the efficiency of the deinking lines to remove stickies has remained practically constant, has result in a lower quality final pulp. Macrostickies on deinked pulp varied from around 300-400 mm^2/kg during 1996-1999 up to 500-600 mm^2/kg during the period 2002-2005.

The large number of potential sources of stickies and their interaction with various additives used in papermaking makes very difficult to avoid all the problems involving stickies and there is not one single control strategy to manage all the problems related to them. Several approaches for stickies control have been proposed in the literature (Blanco *et al.*, 2002; Delagoutte, 2005; Hubbe *et al.*, 2006). These approaches are based on a) limiting the stickies entering to the process by controlling the quality of the recovered paper and/or using recycling-friendly adhesives, and b) controlling stickies in the process.

As the capacity of the deinking lines to remove the income content of stickies has remained practically constant and there is a higher use of adhesives in converting operations, the use of recycling-friendly adhesives is getting more importance. There is an important agreement in the industry that the best option to remove the impact of adhesives in paper recycling is to design recycling-friendly adhesives, to be easily removed in the process as early as possible (Guo *et al.*, 2007). These adhesives can be removed early in the process, ideally using existing equipment and process design (Severtson *et al.*, 2002; Nowak *et al.,* 2003; Guo *et al.*, 2004; Guo *et al.*, 2007). For some years, adhesive suppliers have performed extensive work to develop adhesives less detrimental to the recycling process. However, implementation is still rather limited (Delagoutte, 2005). The first approach was to develop "dispersible adhesives". The idea was to produce dispersible or soluble adhesives, which avoid the formation of primary macrostickies in the pulp. Nevertheless, this approach is now held back due to the high degree of water closure in the mills. Indeed, such products dispersed during pulping increase the load of colloids in the process water and may be responsible for observed deposition phenomena. Consequently, this approach is now practically abandoned and papermakers, who are using recovered papers, ask for the development of "removable adhesives". These adhesives can be removed from the process as early as possible by screening or cleaning process. Although the design of totally removable adhesives is a difficult task, this option is much preferred since it avoids the formation of both primary and secondary stickies. Several options have been proposed in the literature (Yan and Deng, 2003; Oldack and Gustafson, 2005;

Venditti *et al.*, 2007), *e.g.* the development high-density hot melts to be efficiently removed in cleaning operations, the development of hot melts with the melting temperature as high as possible to avoid excessive fragmentation and easiest removal during screening, the development of pressure sensitive adhesives carrying a cationic charge to be easily removable by adsorption onto the negatively charged fibers and fines, etc.

Conclusions

Although the level of recycling in Europe is already one of the highest in the world, there is still some potential for improvement along the paper recycling chain to extend the actual limits of paper recycling, especially in the area of recovered paper availability and quality.

Firstly, there is still potential for an extended collection of recovered paper, especially in the Eastern Europe. If all European countries would collect used paper and board products as effectively as the best ones (80%), 9.5 million additional tons per year of recovered paper would become available. In addition, net trade of recovered paper (8.4 million tons in 2010) could be reduced for domestic industries. Waste and renewable energy policy are of great influence on the availability and quality of the recovered paper. Latest regulations have supported the use of recovered paper for recycling over incineration and the separate collection of recovered paper *versus* commingled collection systems, contributing very significantly to increase the availability and the quality of the recovered paper. It is surprising that environmental awareness is still an important driver for further increase of the availability of recovered paper, even in Western Europe.

Sorting of recovered paper has an important influence on paper quality. Sorting activities are of a great importance especially when lower quality sources are exploited. Sorting is still a mainly manual activity but great efforts are being carried out for more automatization which can effectively contribute to reduce the costs, which have been demonstrated to be the main obstacle for an extended sorting of the recovered paper in Europe. Great efforts have been carried out in sensor-based technologies which will help to extend and improve sorting activities.

Further improvements in paper production technologies can also help to achieve higher recycling. Optimized pulp preparation plants with a high degree of sophistication can treat lower quality sources without being affected the quality of final pulp. The challenge is to further increase the yield, while maintaining the sustainability of the process. Although efforts in the removal of stickies and inks have been carried out, the efficiency of the deinking lines has remained almost constant during the latest years. Associated costs to low quality recovered paper can be a limiting factor, and the mills could not be able to accept lower quality sources.

High recycling rates require that paper products should be manufactured recycling-friendly to keep the recycling cycle running. Recyclability of recovered paper can be achieved through eco-friendly inks and adhesives. Therefore, there is a need of an effective communication between papermakers and printing and converting industries. Paying subsidies and strengthening legislation and regulations could be the solution.

Finally, it is very important to recognize that environmental awareness affects all the stages along the paper recycling chain. Environmental awareness is important to promote not only recovery, but also recycling in general (environmental proattitudes). Consumer interest in environmental issues and the consequent pro-active approach to legislation also result in earlier restrictive environmental legislation, as increased costs for landfill and incineration. Consumers can also help persuade firms to be environmentally friendly and to develop innovative green products and services by the choices they make.

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