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The Economic Aspects of Recycling

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1. Introduction

Over the last years, environmental issues have gained remarkable significance as a result of the high level of environmental awareness in society and also due to the widening of the scope of the environmental legislation and regulation. One of the major concerns within this context is the high rate of packaging waste generation. Nowadays there is a variety of technologies to deal with waste treatment among which recycling is one of the most preferable. Recycling allows waste to be converted in resources and thus its economic value is prevented to be buried in landfill. Back in 2000, the World Business Council for Sustainable Development (WBCSD) proposed improving recyclability as a critical aspect for a sustainable development in business since this end-of-life treatment was foreseen as one of the most sustainable. Furthermore, international legislation regarding end-of-life of waste is pushing stakeholders to adopt more sustainable strategies in the long run. For instance, the European Union Directive 2008/98/EC establishes the five-step waste hierarchy, in which the most sustainable step is the waste avoidance, followed by reusing and recycling. Up until now, waste is taken into account as a product since it is possible to obtain economic benefit from it. After those treatments, recovery (including waste-to-energy) and landfill are considered as the last steps. The day when waste can no longer be avoided and we reach the maximum reuse rate possible, recycling will be the most preferable strategy. This approach is influenced not only by the point of view of the potential economic value of waste, but also by its eco-efficiency.

The benefits of recycling could be summed up in energy savings, natural resource conservation and reduction of waste disposal to landfill. Energy savings of recycling have been demonstrated in a wide range of materials (Stromberg, 2004). The fact of avoiding the use of virgin materials allows reducing natural resources consumption and thus preventing problems to future generations. Moreover, the high quantities and extensions of landfills is a serious disadvantage in a lot of countries like in Japan where land is scarce and it is hard to locate new final disposal sites. Moreover, a great amount of landfill sites are currently full and other solutions should be searched.

Thus, the recycling advantages from an environmental and an economical point of view are influenced by different elements. Environmental and economic life cycle analysis in combination with market studies can be used for the definition of the most suitable waste treatment process in a specific situation.

This chapter is focus on analysing the characteristics of the recycling processes of the main packaging materials, i.e. paper and board, plastics, metals, glass and wood, from an economic point of view. Firstly, a brief market analysis for the recycled materials is carried out, followed by a review of the steps to be considered in the recycling supply chain, and culminates in the description of different methods used for developing an economic evaluation of the recycling processes. Finally, some case studies have been used to illustrate the economic analyses and its relation with both, the environmental evaluation and the sustainability concept.

2. Markets for recycled materials

The market is one of the main aspects to be taken into account to decide whether a recovery process is economically viable. Indeed, there is a vast variety of influential indicators in the market and the prices of the material tend to fluctuate strongly over time.

Both market situation and prices ought to play a decisive role when it comes to choosing the appropriate waste treatment process in a certain context. This is due to the fact that the recycling process depends greatly on the efficiency and effectiveness of the previous and posterior processes needed. Example of such processes are collection of waste, transport, separation, conditioning, as well as post-treatments which are necessary for the transformation of the obtained product to a marketable product.

Obviously, another aspect that should be taken into consideration is the recycled material market price. For instance, as example for plastic waste, the selling price of the recycled material depends greatly on the price of virgin polymer, which is linked to the crude oil price as well as the electricity cost. On the other hand, the prices of the plastic waste bought by recyclers are rarely influenced by the oil price and financial profit influences it more than environmental concern (EuPR, 2010). The price of industrial and consumer waste polymers appears to be modified by:

- The export of materials, above all to emerging countries
- High demand for high-quality recovered plastics
- Collection and sorting companies trying to boost their income
- The plastic characteristics regarding cleanliness, colour, etc.

It should be stated that sometimes the value of waste materials involve negative figures. In other words, the user is paid for acquiring the recovered materials. Nakamura and Kondo (2006) explained that Japanese steel mills accept waste plastic against payment and use them, after pretreatments, as a reduction agent in a mixture of pulverized coal in blast furnaces. Thus, they avoid buying more expensive materials as raw material in mills.

The law of supply and demand is an influential factor on the material price setting. For instance, material exportations to other areas of the world like Asia influence the price. When the demand in the Asiatic market is high, the availability of such material in Europe decreases and consequently prices tend to increase. On the contrary, high availability of either virgin or recycled material usually causes a reduction of prices.

The geographical location plays also an important role in the price setting caused by differences in prices of machinery, materials, and production and labour costs. For example, production and labour costs in emerging countries are known to be lower than in Western countries, but inaccessibility to raw materials could revert to a less advantageous position in the global market. According to statistics, developed countries produce higher waste quantities per person (IPCC, 2006), although high-populated emerging countries like China could vary this trend. Anyhow, recycling constitutes not only a challenge in environmental terms, but also a great opportunity to make profit from it.

Mixtures of recycled and virgin materials can be used instead of purely virgin material in manufacturing processes. Indeed, there are numerous studies showing that the addition of certain amounts of recycled material to virgin, does not damage the properties and characteristics of the resulting material (McGregor, 2009).

However, there are cases where recycling might not be the best way to deal with waste (Leiter, E., 2010). For example, when the price of the recycled material is highly priced with regard to the virgin material, it would be more profitable to choose the recycling option. On the contrary, in periods where the recycled material is low-priced would rather be more beneficial to focus on waste-to-energy technologies and obtain profit from the sale of energy.

On the other hand, recycling could have significant economic impacts as it replaces materials commonly obtained, transported and manufactured outside a specific region with materials collected and processed usually within the region.

Therefore, the selection of the recovery process that performs best in a given context requires a multi-perspective approach including issues such as financial cost, environment, market, supply, demand, etc.

2.1 Paper and board

The major paper producers in the world are Asia, the CEPI countries[1] and North America. These figures are closely related to population and level of industrialisation of countries. According to CEPI 2009, the paper production decreased as a result of the world economic crisis in 2008 and still continued in 2009. This fact was partially balanced by the pushing of the Asiatic countries, especially China (RISI, 2010). Nevertheless, pressure on the recovered paper sector set up by governments appears to explain part of the statistics and the use of this material in the paper and board industries at the expense of virgin fibres. In 2010 the negative tendency was reversed and the utilisation of recovered paper was increased. On the other hand, 2009 was the fourth year in which generation and consumption of recovered paper outstripped virgin fibres ones, but it should not be forgotten that virgin fibres are indispensable in producing high quality paper. Furthermore, the use of fresh fibres is required to strengthen the mixture of recovered paper during the papermaking process (METAFORE, 2006). This is due to the degradation that fibres suffer in the process of recycling and the use of recycled fibres usually varies between three and eight times depending on the quality of the recycled paper.

[1] CEPI countries are as follows Austria, Belgium, Finland, France, Germany, Italy, The Netherlands, Norway, Portugal, Poland, Spain, Sweden, Switzerland, United Kingdom, Czech Republic, Hungary and Slovak Republic.

Taking a look at the figures for the consumption recovered paper[2] in Table 1, the influence of Asia is stated. The differences between collection volumes and apparent consumption are explained by quantities in stock by collectors and consumers at the end of the year and a certain quantity of paper cannot be taken advantage like the toilet paper.

	Collection (tonnes)	Imports (tonnes)	Exports (tonnes)	Apparent consumption (tonnes)
Asia	83,108,000	35,980,000	7,710,000	111,334,000
Europe	62,980,000	12,950,000	24,650,000	49,250,000
North America	49,900,000	1,650,000	20,880,000	30,670,000
Latin America	10,020,000	2,105,000	670,000	11,455,000
Australasia	3,340,000	160,000	1,470,000	2,096,000
Africa	2,140,000	90,000	60,000	2,172,000
Total	211,488,000	52,935,000	55,440,000	206,977,000

Source: Magnaghi, 2009.

Table 1. Consumption of recovered paper in 2009.

By countries, the Table 2 shows the importance of Asia and particularly China as it comes to imports of recovered paper.

Imports of recovered paper		
Country	2008 (tonnes)	2009 (tonnes)
China	24,200,000	27,500,000
Germany	3,556,000	2,860,000
Netherlands	2,472,000	2,964,000
Indonesia	2,080,000	2,290,000
India	1,755,000	2,135,000
Belgium	1,500,000	1,536,000
Mexico	1,436,000	1,510,000
South Korea	1,307,000	1,120,000
Austria	1,305,000	1,190,000
Thailand	1,218,000	970,000
Spain	1,170,000	902,000

Source: Magnaghi, 2009.

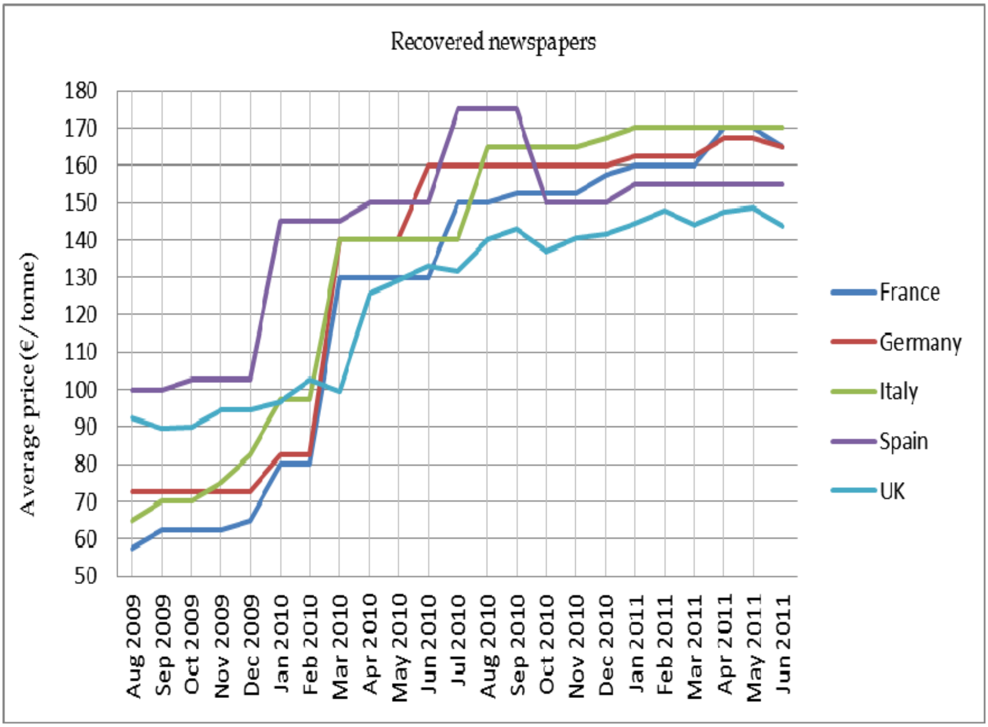
Table 2. Major importers for recovered paper.

Although, most of the recovered paper is consumed in the country of origin, the exports are measured in millions of tonnes and represent a huge international market since is the main material used to make new paper such as newsprint for newspapers and cardboard for

[2] Recovered paper consumption is calculated as the recovered paper collected plus imports minus exports

packaging. Asia remains the most significant importer area due to the constant development of its paper and board industries. Regarding China, a fact that normally is not considered is that over the last years the Chinese government has encouraged to close many traditional mills because of uneconomic or focus of serious water pollution problems. In return, modern factories with highest capacity have been built principally in the east coast (Magnaghi, 2009). As a result, the China´s capacity for processing recovered paper has been increased and estimations assure that this fact will continue in the next years. Thus Chinese producers arbitrate the world market export pricing.

As far as recovered papers prices are concerned, the price of selling them is rather dependant of their quality and desirable uses. For instance, according to EN 643 "European List of Standard Grades of Recovered Paper and Board", recovered paper grades can be divided as mixed grades (1.01), corrugated and kraft (1.04), magazines (1.06) and deinking paper (1.11). As a summary, in the Figure 1 the price of recovered newspapers is shown. One can state the extremely variations from both perspectives, the modifications in a country and the comparisons between countries. The reasons for these figures have been explained previously in section 2.



Source: RISI

Fig. 1. Average price of recovered newspaper for selected countries.

2.2 Plastics

Plastic waste can be recycled by mechanical and chemical recycling. Not all plastics can be recycled since there are chemical difficulties that make it impossible or with undesirable results. Mixed plastic packaging is not usually recycled due to problems in the separation stage and it is under research currently as it comes to collection and processing. Nevertheless, there are initiatives in order to adapt it to the industrial scale. Thus, the plastics which can be recycled are PET (polyethylene terephthalate), HDPE (high density polyethylene), LDPE (low density polyethylene), PP (polypropylene), PVC (polyvinyl chloride), PS (polystyrene) and others. The new uses range from jackets, coat and food packaging for PET. HDPE can be recycled in order to make tables, roadside curbs, benches, lorries cargo liners, trash receptacles, etc. LDPE is used as shop bags after the consumer stage. Recycled PP is suitable as small beans and battery boxes. Recycled PVC is appropriated for making weep pipes. PS can be converted in flowerpots. Furthermore, uncommon products from recycled plastics are being studied in order to add value to these materials. Examples of such innovations constitute the intelligent textiles (Greenpac, 2011).

World plastic production had been increased from 1950 to 2008. In 2008 the economic crisis made total tonnes of produced plastic to drop, but it seems like it is slowly recovering in 2010. The higher demanders of plastic are the NAFTA countries[3], Western Europe and Japan. Focussing on the European market, the demand for plastic was in 2009 as shown in Table 3.

Polymer	Demand in percentage (%)
LDPE	17
HDPE	12
PP	19
PVC	11
PS	8
PET	8
PUR (Polyurethane)	7
Others	18

Source: PlasticsEurope

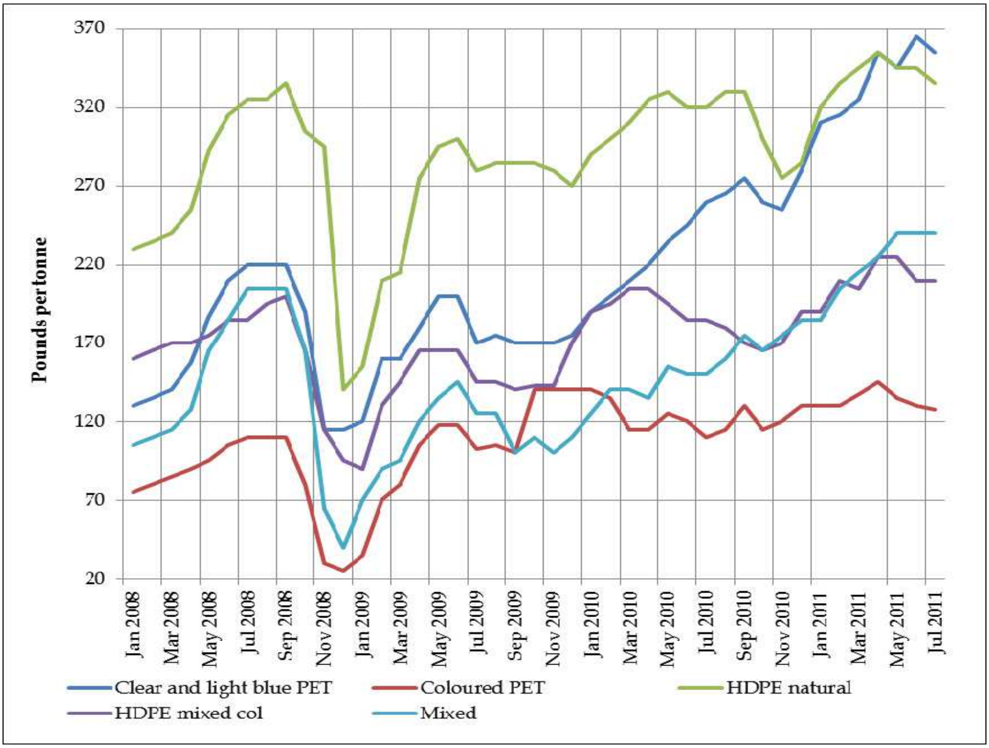
Table 3. Plastics demands by converters in 2009. Breakdown by types.

Plastic recycling has been increasing its tonnage by around 11% per year over the last 10 years in Europe. Nevertheless, as stated above, in 2009 this growth fell to 3.1% as a direct impact of the economic crisis. This number is also explained by stronger activities of some packaging collecting and recycling systems and the increment of the exports outside of Europe, i.e. to the Far East. Derived from these facts, the quantity of plastic that end its life in landfill is reducing.

[3] NAFTA: North American Free Trade Agreement is a trilateral trade bloc established by the governments of USA, Canada and Mexico

As it comes to the Asian market, the same tendency is observed. From 1990 to 2008 waste plastic trade was increased by 100 times as a result of the increasing demand of such material. High prices in oil were related to high prices in virgin plastics which caused an increment in recovered plastic demand. Thus, 80% of waste plastic was sent to Asia in 2007.

The most common plastics which are currently recycled are PET and PE as it comes to prices of recycled plastics. The data figures are usually presented varies with the type of plastic. As an example, the PET prices differ from whether the material is in form of bottles or flakes, if it is colourless or mixed colour, or if is suitable for food contact (food grade) or not. In Figure 2, the prices for recycled plastics are presented for the British market.



Source: Letsrecycle.

Fig. 2. Average prices for different kinds of plastic bottles in the British market.

A clear drop in 2008 and the subsequent increment are shown for high quality sorted materials such as PET and HDPE bottles. High demand from Chinese processors, depreciation of currencies against the US dollar[4], increasing demand for food grade recovered plastics, tight domestic supply, related to the lower consumption due to crisis and higher virgin plastics prices can explain this behaviour. Plastic demand is strongly sensitive

[4] Prices are typically set in US dollars

to consumer spending habits, and therefore, economic downturns. Nevertheless, a recovery is observed for every type of plastic. The line for mixed plastic bottles remains more horizontally than the other kind of recycled plastics because of uncertainties in their process of recycling and the need to study deeply their recyclability. On the other hand, and focussed on the plastic container sector, disruptions are influenced by mergers and acquisitions of companies especially in the USA due to large players that are fighting in a mature market.

2.3 Metals

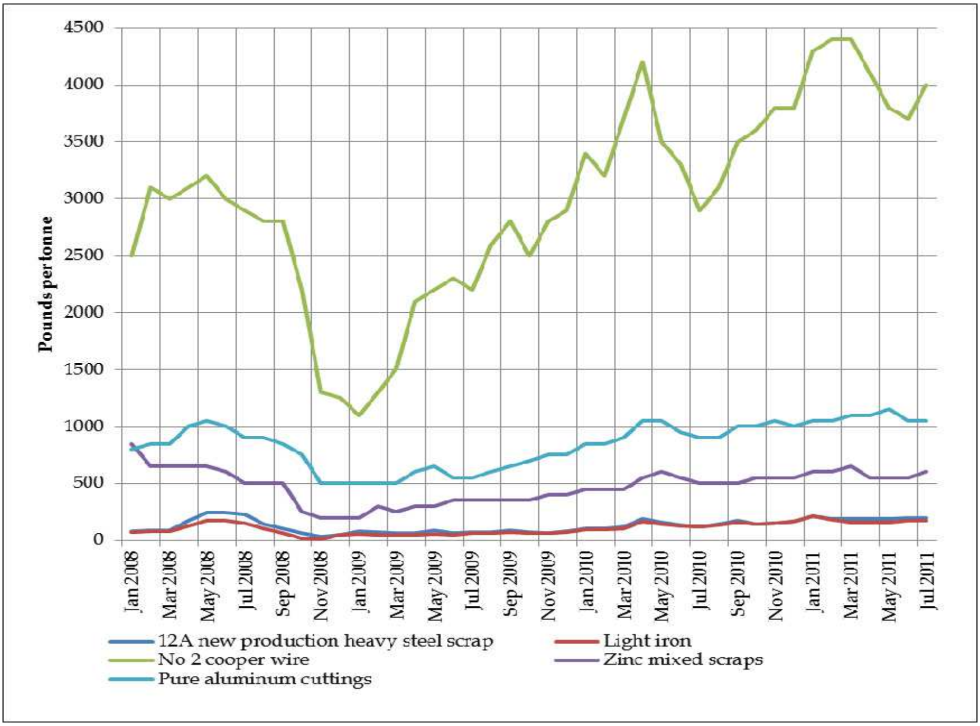
The advantages of recycled metal versus virgin one, from an environmental point of view, are the lower use of natural resources and the savings in the energy required for its processing. Recycling saves 95% of energy in aluminium production, 85% in copper production, 74% in steel production, 60% in zinc production and 65% in lead production (BIR, 2009). In economic terms, this is translated to savings in the energy bill and the possibility of taking profits from an interested market. Such importance lays on the metal market has raised their demand in China, India and the Far East due to the development of the commercial, residential and industrial construction. Moreover, industrial machinery, cars and armament demand these materials. Metal scraps help the primary metals industry to achieve these needs not only in the developing countries, but also on the Western countries.

Steel is by far the most-recycled material in the world, followed by paper and aluminium. As it comes to economic figures, the main exporters in 2010 were USA (20.56 million tonnes), the European Union with 18.97 and Japan (6.47), whereas the main importers were Turkey (19.19 million tonnes), South Korea with 8.09 and China (5.85) (BIR, 2010).

The steel scrap consumption in the European Union increased in 2010, whereas USA slightly reduced it in that year. The main reason for that behaviour is that electric arc furnaces (EAFs) only consume steel scrap because of saving in energy consumption, but were operating at lower rates. Moreover, the EAFs in USA utilized around 40% iron alternatives.

Asia had become a net centre of recyclable import with the 80% of the world's copper scrap imports, the 50% of the aluminium scrap and the 30% of iron and steel scrap in 2007. China has converted in the world leader in steel production.

Figure 3 shows the prices paid by medium to large size recycling companies which receive material from local collectors. As shown in Figure 3, the economic crisis has not influence the metal prices so deeply in comparison with the previous materials and prices are recovering slowly. This is due to the constant demand of these materials. For instance, in the aftermath of the recession the steel production in the world reached 1.412 billion tonnes in 2010, which represented an increase of 14.8% over 2009 and a new record (BIR, 2010). Only copper reduced its price in 2008 and roller coaster movements have been done in the last months. This uncertainty in the price is partially due to the crisis of the Europe sovereign debt, the downturn of the America´s economy and the process of restructuring the Chinese economy.



Source: Letsrecycle

Fig. 3. Average values of scrap metal prices in the British market.

Not surprisingly, the price of non-ferrous metals is appreciably incremented in comparison to the one of the ferrous metals. The main reason is the limited availability of those materials, so the unrestricted flow of non-ferrous scrap from country to country is crucial according to the law of supply and demand.

The precious metals constitute a very special case. The precious metals´ price is increasing almost continuously. They act as a safety refuge when global markets are unstable. Furthermore, when the price of oil is moving up and down, investors look for these kinds of metals with relative stabile value on the market.

2.4 Glass

The process of glass recycling is quiet interesting from an industrial and environmental point of view. Glass can be recycled endlessly without losses in quality or purity (GPI, 2010). Energy costs drop around 2.5% for every 10% cullet[5] used in the manufacturing process. In addition, cullet makes the manufacturing mix less corrosive and reduces the melting temperature extending the furnace life. Moreover, glass recycling is a closed-loop system which does not produce additional waste or by-products (GPI, 2010).

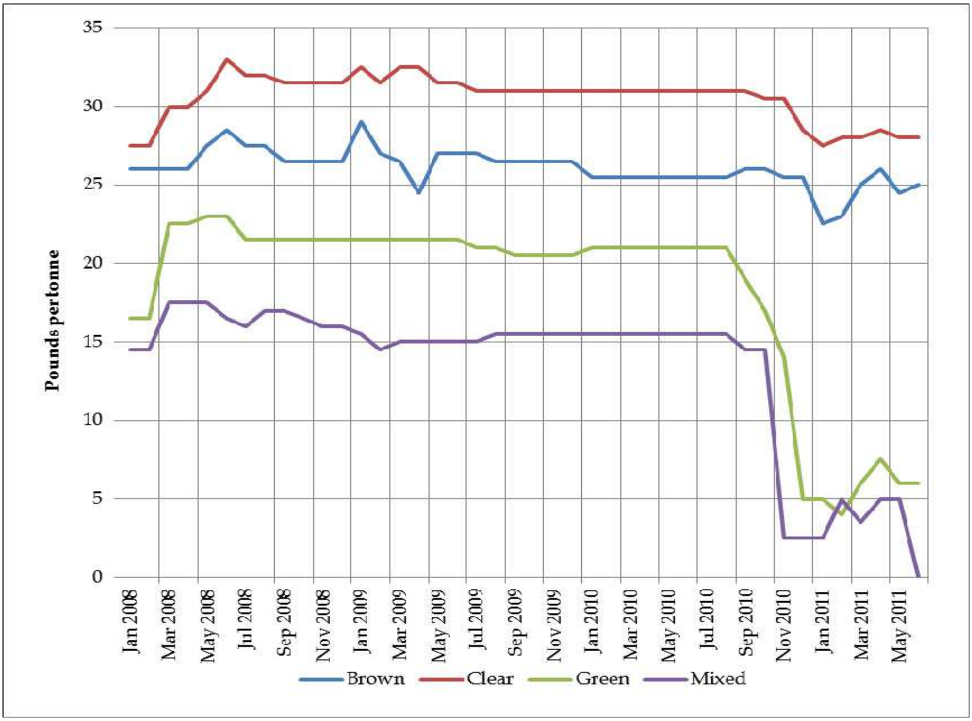
[5] Cullet: Glass crushed and ready to be remelted.

Demand for cullet has grown over the last years with new glass processing plants and alternative markets under developing. Thus, the domestic market for recycled glass remains usually at high level and this fact makes the price paid for this material to be quite stable. In most countries this circumstance is added to the non-dependence of the glass industry on the export market. As a result, long-term contracts between local authorities, which are the main providers of glass for recycling, and glass recycling companies come with a good degree of security.

On the other hand, in the last years companies have adopted strategies in order to improve their environmental credentials as a way of making their green marketing better. Derived from this fact, actions like reducing the weight of their glass bottles in important percentages have been doing. 99% of glass containers in the world (in weight) belong to food packaging and it is easy to imagine the global avoided impact of these actions.

Imports and exports in the glass market are rare because of its high weight and the high fuel consumption associated to their transport which increases prices. Moreover, multinational companies have plants in several countries and the raw material recovered glass is mainly provided by the national market.

In the Figure 4 the prices of glass containers in the British market are shown. Completely mixed glass has the lower value due to strange colours obtained after melting. This fact makes



Source: Letsrecycle

Fig. 4. Average values of glass prices of containers delivered to collectors in the British market.

it difficult to sell it since customers demand pure colours. Instead, it should be derived to alternative uses. Green glass has the third lower price because it is the most abundant in the United Kingdom waste stream. The clear glass is the most expensive since it is the most demanded one in this market. Nevertheless, internal issues could affect the glass price. For instance, in the Figure 4 the slump in prices from September to December of 2010 was related to the continual decline in Packaging Recovery Notes[6] revenues (Letsrecycle, 2011).

Apart from glass containers, alternative uses of recycled glass are coming out. Such new approaches include glass as grit blasting, use in road surfaces or water filtration.

2.5 Wood

As it comes to recycling of wood, two types of materials should be distinguished. i) High grade wood comes from clean white softwood, wooden pallets, timber offcuts, packaging crates and joinery waste. They should be free of paint and coverings. ii) Low grade wood includes plywood, doors and window frames, roof timbers, panel products and so on. Both kinds of materials come from construction and demolition, commercial, industrial and household sources.

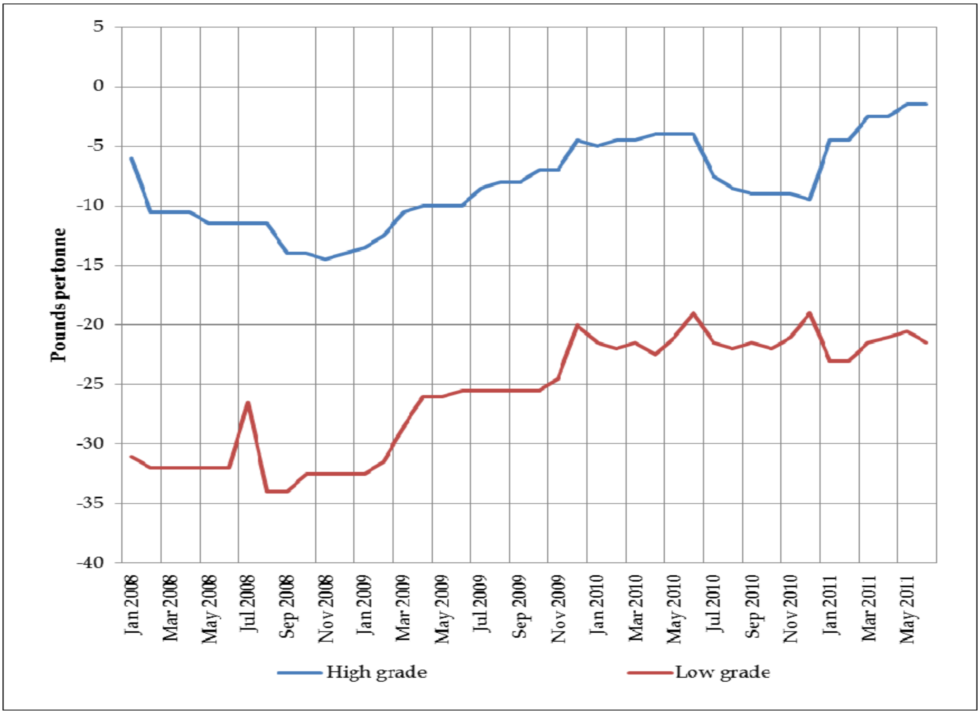
The main market of recycled woodchip has been the panel board industry due to historical reasons. This material is used in the production of chipboard. Nevertheless, the wood industry has been searching for value-added markets and new uses have been discovered, i.e. animal bedding, equine surfacing, garden mulches markets have steadily developing. This fact has made wood industry to increase in the last years. The demand of woodchip is expected to continue growing since governments are promoting the generation of renewable energy.

In the Figure 5, the price evolution of recovered mixed wood delivered to a wood recycler can be seen. Negative prices indicate that the recycler is paid for these materials. Nevertheless, this fact can change because of increasing demand of clean wood pallets and sawmill round wood towards small payments by suppliers. In addition, wood waste prices will vary considerably depending on cleanliness of the material, volume and location.

3. The recycling supply chain

Recovered waste materials, before being recycled must be collected, transported and separated among other processes and as a result, the general performance of the recycling process depends greatly upon the efficiency and effectiveness of those “minor” processes. Similarly, from the economic perspective, the recycling process must be preceded from also efficient and economic sub-processes. Otherwise, high cost of recycling could overweigh the environmental benefits of recycling. In addition to the recycling process itself, a broader approach including the prior and posterior stages of recycling is needed.

[6] Packaging Recovery Notes is a document which provides evidence that waste packaging material has been recycled into a new product in Great Britain.



Source: Letsrecycle

Fig. 5. Average values of wood prices of mixed wood delivered to a wood recycler in the British market.

3.1 Collection

The municipal solid waste generated in the European Union was 514 kg per inhabitant (Eurostat, 2010) and 719 kg in the USA (EPA, 2010) in 2009. Such high quantities should be treated under the most convenient processes. The end of life of materials starts wherever is produced, whether it is generated in a house, store or industry. It is necessary to separate out waste in appropriate fractions according to the facilities in which they are going to be treated in order to make further stages more effective. Throughout this action waste is treated easily and economic costs are reduced, allowing making recycling a competitive treatment. Ideally, waste should be set apart as paper and board, plastic, metals, glass, wood, batteries, textile and organic. This can be done at source, having selective collection in the cities or at specific sorting plants, where all recyclable materials are sorted out and sold to recyclers. Nevertheless, the availability of these facilities varies from country to country and is close related to environmental policies.

Transport plays an important role in the collection stage. A wide range of vehicles can be used, but lorries have become as the most used in this issue due to their load capacity and the particularities of towns. Furthermore, these vehicles can sometimes incorporate a pre-waste disposal unit which enables compacting waste and making collection more effectively.

3.2 Sorting

Once waste is collected, sorting is a mandatory activity in order to have separated the different recyclable materials and to avoid undesirable materials which can decrease recycling efficiency and recycled material quality. For example, ceramic is considered a disadvantageous material when glass is recycled. Furthermore, separating a material in specific fractions (for instance different colours, etc.) allows taking advantage of differences in sell prices as has previously been shown in the elements studied. Paper and board´s costs differ on the quality of fibres and, at the same time, on the origin. Plastic should be separated according to the type of resin because some recycling processes are specific of each material. For instance, methanolysis only works with PET polymer (Aschilias, 2004). Glass is required to be sorting according to its colour. Coloured glass is unable to produce clear one and mixed glass presents the lower price. Metal values depend on their kind as we have seen and sorting is a must in order to separate them according to their nature.

The cost of sorting depends on the technique selected. For example, in case of using optical separators the purchasing cost of the equipment could be more expensive than carrying out a density separator, i.e. a pool with water and salt (to increase the density) or alcohol (to reduce it) is enough for separating plastics. However, this last treatment could lead to an increment in the final cost by considering also the price of energy in order to dry wastes as well as the substances used for adapting the water density and the water treatment after the process.

Then we have two flows: the materials which will continue with the recycling process and the sorted materials that can be sold in order to obtain revenues.

3.3 Shredding

Shredding is required before the recycling process and is considered a key pre-treatment since it facilitates further processes. Its main advantage lies on the volume reduction, which minimize the storage space as well as reduce transportation. Moreover, as it comes to glass, it allows reaching the melting point by using less energy and time, and improving furnace feeding. Small pieces increment their surface exposed and the energetic yield. Thus, less fuel is required in order to melt glass and metals. It is desirable that metals arrive at the processing facility in bales or briquettes since this way the efficiency of the remelting process is increased. Nevertheless, the most common is not to receive such material in this form and a shredder constitutes usually a stage in the recycling facility. In addition, it helps to liberate trapped contamination, upgrading the quality of materials like glass, metals or plastics and its value. On the other hand, the shredding of paper and wood is not high recommended since fibres will be damaged. Wood recycling requires shredding when the final use is to make agglomerate boards or smaller pieces.

3.4 Recycling process

The recycling process differs depending on the material to be treated. The recovered paper is put in a pulper with water and is pulped with mechanical and hydraulic agitation in order to disintegrate paper into fibres. For purposes of deinking some chemicals are sometimes used, like deinking agents and NaOH. Contaminants are removed during the operation due to differences in physical properties. The pulp slurry is pumped from the pulper to hydrocyclones. The organic rejects are often burned in order to take advantage of their calorific value. In general, screening at lower consistency in order to separate undesired particles is more effective, but it requires additional machinery installations and its energy consumption of the process is increased (INERIS, 2010). After that, a fractionator is used in order to separate the pulp in two fractions, creating a short-fibre stream and a long-fibre one, to apply different treatments. In the case of long-fibres, dispersion can occur with the finality of achieving better fibre-to-fibre bonding, strength characteristics, and to reduce dirty specks in size. Furthermore, refiners improve optical and strength characteristics, but its main disadvantage is the impressive energy consumption. Continuing with the industrial paper recycling process, the mixture enters in the paper machine after a cleaning substage and a fine screening (INERIS, 2010). Moreover, a flotation deinking stage is recommended when recycling paper so that ink is removed and a better brightness is followed. In addition, bleaching chemicals can be added before entering at storage tower. Finally high quantity of waste water is produced during the process and should be conveniently treated in order to reduce pollution.

In case of plastic recycling, after sorting and shredding, a washing step should take place in which impurities are removed. Next, the melting process is done throughout an extruder which applies heat by friction. It also allows homogenizing and filtering in order to produce high quality recycled material. In the end, the pellet conformation is produced by a pelletizer.

The recycling process of metals consists of a melting process. The temperatures should reach from hundreds to thousands degrees, but alloys can reduce such high values, high energetic costs, to a more reasonable one. There are particularities in the melting process due to the wide range of recyclable metals and stages for overcoming potential problems. For example, as it comes to aluminium alloys, a degassing step is necessary to reduce the amount of hydrogen in the liquid metal. High hydrogen concentration could result in gas porosity that deteriorates mechanical properties. Continuing with the process, the molten metal is poured into molds. Once the metal is solidified, it is removed from its mold. A degating stage is necessary in order to remove head, runners, gates and risers from the casting (AFSSOCAL, 2011). For this purpose, cutting torches, bandsaws or ceramic cutoff blades are used. This metal must be remelted as salvage increasing, thus, the yield and reducing the costs. Surface cleaning is needed for a better presentation. Usually, sand or other molding media might be adhered to the casting and metal is cleaned using a blasting process. In other words, a granular media is propelled against the surface of the casting. The media, propelled by compressed air for instance, strikes the surface at high velocity and tears any impurity of the surface. Finally, grinding, sanding or machining steps are done in order to achieve the desired dimensional accuracies, physical shape and surface finish, as well as painting in case prevention of corrosion was needed and improve visual appeal.

Once again, melting is also the main step in the glass recycling process. Cullets are melted in huge furnaces. Decolorizing and dyeing is the next stage. Firstly, oxidizing of the melted glass cullet is required. For green glass, the colour turns from green to yellow-green and manganese oxide is then mixed until a grey colour appears (All-recycling-facts, 2009). For brown glass, zinc oxide is added to oxidize it to blue or green cullet. If clear recycled glass is required, erbium oxide and manganese oxide are added to help clear all the colours from the glass cullet. In the end, the recycled glass is moulded into the final product.

Taking into account that contaminants have been removed before, the recycling process for wood consists in a two-steps process in which wood is introduced in a tub grinder, horizontal grinder or wood chipper. Wood is grinded into chips which are ready to be sold for use in particle board, chipboard, pulp and paper products, animal bedding, mulch, biomass fuel and compost. In the panel board industry, an adhesive is necessary to stick wood pieces together.

3.5 Distribution of recycled material

After recycling, two additional steps should be also considered: packaging and transport to customer. As it comes to packaging, the type is influenced by the transported material. Paper is carried in coils, and for plastic pellets sacks are usually required. Moreover, metal and cardboard can be transported with strapped sheets. Glass recycling and manufacturing are done in the same facilities and transportation to glass maker is not required, although transport from glass maker to filler is needed. Here, packaging entails of palletizing and shrink wrapping. Initially, the distribution stage does not modify substantially the purchasing cost of the recycled material, but it is greatly influenced by the distance, weight and way of transport.

4. Economic evaluation of recycling

The aim of the economic evaluation in recycling processes is, on the one hand, to assess the economic impact of recycling and on the other hand, to identify weak points, or the less economically efficient stages of the process, in order to be improved. This data is valuable for decision support from a public and private point of view. In regard to public organisms, it allows to select the best waste treatment alternative. As it comes to private companies, it also provides information about the recycling process´ profitability and recovery.

The economic evaluation of recycling processes can be determined through several methods. Some of the most relevant are the Life Cycle Costing (LCC), the Cost-Benefit Analysis (CBA) and Input-Output methods. LCC is a method which follows a life cycle perspective. All the inputs and outputs are determined in economic units and several types of LCCs can be found (see section 4.1). CBA has been developed for major public investment plans and compares the total expected costs against the total expected benefits. This way the difference between costs and benefits is determined and measured. The Input-Output method is a linear model in which the interdependencies between links in a chain are presented on the basis of the output of one industry is the input of another. This quantitative economic technique is used to compare branches of national economy or between competing economies.

Despite the fact that the economic evaluation of recycling can be worked out throughout diverse methods, in this chapter LCC will be the most selected economic method since it is a precise and useful tool suitable for economic evaluation of recycling.

4.1 Life cycle costing

LCC analysis, which is a cost management method, is carried out on existing products and is used to monitoring and managing costs over the product or process life cycle. From a time perspective, it can be used for comparing past alternatives or future ones.

Environmental LCC analysis is a methodology that allows:

- To identify the processes that are most relevant for the overall cost
- To compare life cycle costs of alternatives
- To detect direct and indirect (hidden) cost drivers
- To identify trade-offs in the life cycle of a product
- To use the full costing to identify new products

One of the first steps to carry out a LCC is to determine the functional unit (FU) to which all the costs will be referred. Examples of FU in a recycling process could be one tonne of recycled product. However, the FU should be adapted to the specific case considered in order to reflect the real costs. For instance this means considering the same time frame for all costs and including, if necessary the effect of inflation. The system boundaries should also be defined. System boundary limits which stages, inputs and outputs are taken into account in the LCC. Ideally, considering the whole life cycle is the best, but sometimes it is impossible due to missing data. In this case, one can make a bibliographic search to overshadow the handicap, although in case of not finding the data the system boundaries should be modified. All the data will be expressed in economic terms and converted into present-value costs by using discount rates. Another piece of advice highly recommended is to break LCC in cost elements so that it is easy to use. Not all costs should have a great impact on the final results, but breaking costs constitutes a good starting point aim at considering those that contribute most to the total cost.

There are many ways to classify the costs involved in a LCC. One of them is the approach of (Bovea, 2003) according to which the costs are:

- **Internal costs (IC)** along the life cycle of the products (i.e.: production, use or end-of-life expenses), which are the costs for which the company is responsible over a period of time. These type of costs include:
    - Conventional costs (CC): direct costs borne by the company when manufacturing a product (i.e.: raw materials, electricity, transport, etc.).
    - Hidden costs (HC): general costs related to license expenses, waste management costs, etc.
    - Less tangible costs (LTC) which are often not included in the company accounts due to their probabilistic nature. These costs include expenses on marketing, improving the image of the product, safety measures for workers, etc.
- **External costs (EC)** that are envisioned to include monetized effects of environmental and social impacts not directly billed to the company, consumer or government. These costs are also called "externalities" on life cycle management forums (like costs related to depletion of natural resources, impact on human health). Quantifying of negative effect of external costs is a critical issue in LCC practice. According to Kloepffer (2008) external costs to be expected in the decision-relevant near future (e.g. cost occurring in the future due to legal requirements in order to fight against climate change or special

requirements for radioactive waste) are difficult or even impossible to estimate. Several attempts for the monetisation of external costs have been done, i.e. monetisation of emissions, road congestion and noise negative effects.

(SETAC, 2008) proposed the definition of the internal costs as the costs "*directly borne by an individual or organization in supplying or consuming a product*". And the external costs were defined as "*the market costs, not directly borne by an organization in terms of costs of labour, capital, and taxes, but as costs for purchases from other firms in the system, covering the internal costs of these other firms*".

Consequently the LCC can be calculated as follows:

$$\mathbf{LCC = IC + EC = (\Sigma\ CCi + \Sigma\ HCi + \Sigma\ LTCi) + \Sigma\ ECi}$$

Figure 6 represents the stages of the life cycle of a product. As can be seen, the life cycle of a product can be a close-loop in case recycling is used as a waste management. Costs in LCC correspond to the stages in life cycle. This way, finding the most disadvantage phases is easy.

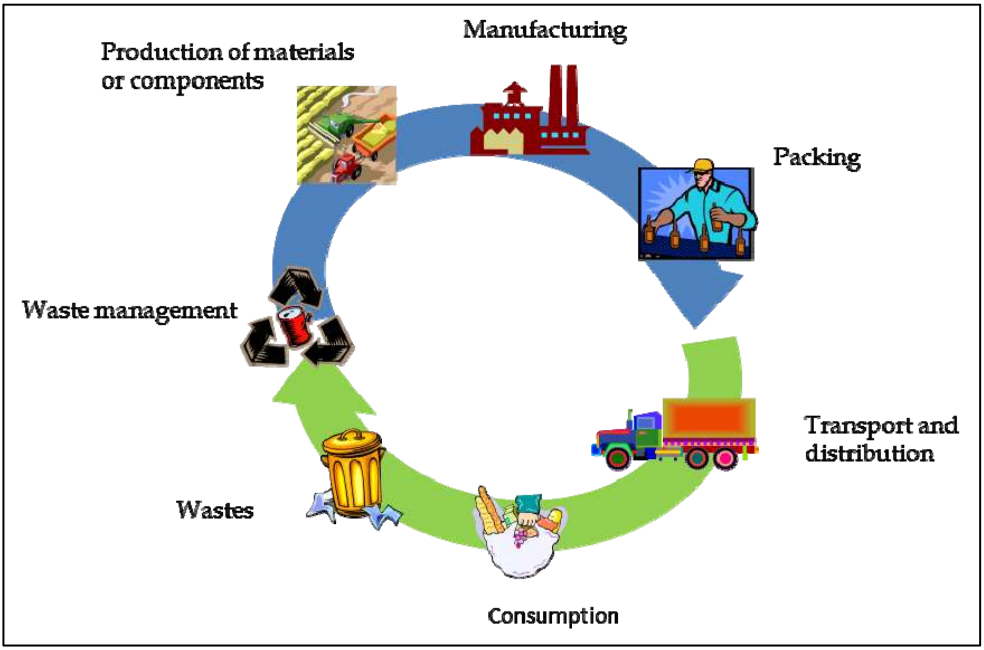


Fig. 6. General life cycle of a product.

The SETAC-Europe Working Group on Life Cycle Costing has defined three types of LCC, depending on the costs considered in the study: conventional life cycle costing, environmental life cycle costing and societal life cycle costing (SETAC, 2008).

4.1.1 Conventional LCC

The assessment includes only internal costs excluding on some occasions the End of Life (EoL). The perspective usually refers to one actor: the manufacturer, the user or the consumer. The conventional LCC is similar to the profit-loss account carried out by companies and does not include social impacts. It is usually not associated with separate LCA results.

4.1.2 Environmental LCC

According to (Rebitzer & Hunkeler, 2003) and (Kloepffer, 2008), environmental LCC may be defined as "*an assessment of all costs associated with the life cycle of a product that are directly covered by any one more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor), with complimentary inclusion of externalities that are anticipated to be internalized in the decision-relevant future*".

The assessment includes internal cost plus external costs expected to be internalized. Complete life cycle is taken into consideration and the perspective used may refer to one or more actors. Environmental LCC takes into account the financial costs associated to environmental impacts from LCA. The fact of using the same functional unit allows the comparison between LCA and LCC. This type of LCC allows the assessment of costs along the life cycle of a product maintaining the economic pillar of sustainability separately from the environmental and social pillars.

4.1.3 Societal LCC

The assessment includes both internal and all external costs and complete life cycle is considered. The perspective refers to society including governments and considerers both, the present and the long-term future possible situation. Societal LCC includes all of Environmental LCC and additional external costs (SETAC, 2008).

The main difference among the three types of LCC is that only environmental LCC follows a functional unit as a reference unit for the economic assessment. This aspect is extremely important, since the environmental LCC is the only kind of LCC that follows the same approach like LCA. Although not existing an international specific methodology for carrying out LCC studies, the reference (SETAC, 2008) can be used to carry out this kind of analyses.

Once the types of LCC and costs are explained, a review of some case studies will be carried out in order to know more about this kind of analysis and better understand how to interpret the results.

4.2 Case studies

In section 4.2, the description of the main techniques and problems regarding LCC in recycling is shown by reviewing case studies. It is of the opinion of the authors not to show all the results since they would change depending on the case studied, country and year of the study.

4.2.1 Selection of alternatives based on economical parameters

As has been stated, LCC can be used to select the best economical alternative in the EOL of products. Craighill & Powell (1995) carried out a study on recycling household waste from economic and environmental points of view. They quantified the cost of recycling aluminium as 111.41 £/tonne, glass 67.20 £/tonne, paper 73.79 £/tonne, steel 31.64 £/tonne, HDPE 12.07 £/tonne, PET 21.25 £/tonne and PVC 11.55 £/tonne. When comparing the recycling cost with the waste disposal cost of every material, the net benefits were favourable to recycling except in the cases of plastics.

As an example, in 1999 the more attractive economic end-of-life of municipal solid waste was disposal with an average value of 105.91 $ per tonne in the state of Maine, United States, whereas in the case of recycling it cost 107.37 $ per tonne (Maine, 1999). Although each region faces a very difference set of circumstances, this fact would be extrapolated to other areas. From the actual point of view, it is clear that recycling technology has been constantly upgrading and advances in the state of the art allow reducing cost. Moreover, legislation is pushing stakeholders to adopt the environmentally best alternative in EOLs of materials.

A special case appears when recycling contaminated waste. Chang & Farr (2000) focused on contaminated low-level mixed waste pre-processes. They centred their efforts on a multiobjective evaluation to treat heavy metals, radio-nuclides, PCBs, halogens, pesticides and chlorinated waste. This study constitutes an example of some problems that decision-makers should face when one or more strategies of recycling of waste with hazardous materials. Firstly, it is necessary to determine which contaminant or contaminants are tainted within waste. Secondly, the targets are not only costs and resource recovery, but also volume reduction, simplicity of process, health risks and energy efficiency. Thirdly, a review on the technologies and their costs is necessary. Once these stages are reached, the authors proposed a partially subjective evaluation in order to have a single score with which being able to select the best option depending on the type of impurity.

Once the LCC is carried out, several tools can be used in order to prioritise the components recycling of a product. Park et al. (2006) used four methods to help decision-makers to prioritize washing machine components to be recycled from an economic and environmental perspective. The four methods selected were the two-dimensional diagram, eco-efficiency, the monetary method and the multi-attribute decision making (MADM). The two-dimension diagram is a graphical representation of the environmental impacts of components calculating in a LCA along the X-axis and the economic values, for instance as benefits or selling prices, along the Y-axis. Eco-efficiency was worked out as the ration between the economic benefits in the numerator and the environmental impacts in the denominator. Derived from that, a component that has a lower economic benefit and higher environmental impact is considered to have the highest priority in improving the economic and environmental performance. In addition, this fact is considered a key issue in ecodesign. The monetary method consists of expressed the environmental impact as monetary value. There are several tools in order to make this like the LIME method. This way the environmental and economic results are in the same units and adding or subtracting is easy. MADM is used in selecting one or more alternatives or ranking from a multiple alternatives.

Numerous methods have been proposed for carrying out the MADM. Among others, the simple additive weighting (SAW) was selected by the authors. The SAW method runs as the weighted sum of the performance ratings of each alternative based on the evaluation of all criteria.

The authors reduced variance of prices of recycled materials by selecting average sale prices. Moreover, weighting factors were used since 0.25 corresponded to environmental aspects and 0.75 to economic ones. The study showed similar results for the two-dimensional diagram, the monetary method and the MADM for the recycling of the washing machine components. The results of the eco-efficiency were slightly different. This fact sums up the answer of how important is to considered additional analysis beyond LCC and LCA. By applying several methods the information on the recycling process is more complete and stakeholders are in a better position to make decisions.

4.2.2 Influence of product design or the kind of material in recycling

According to Porter (2002) recycling has two major financial costs: collection and reprocessing. This is true only in the cases in which recycling involves a single recyclate, such as PET or PE. When a product is compounded by more than one material, the influence of the design is highlighted.

Nakamura & Kondo (2006) proved that dissembling is the first and most important stage in the recycling process as it comes to electrical home appliances (TVs, refrigerators, washing machines and air conditioners). Nevertheless, this idea is likely to be extended to different kinds of waste like cars, industrial machinery, etc. all of which are compounded by several materials. The design for disassembling increases the efficiency of disassembling and raises the purity of some recovered materials, in the end the selling price. Improving the design for disassembling means saves from both an economic and environmental point of view (Nakamura & Kondo, 2006). Costs and revenues are determined to a high percentage in the design phase, and thus the importance of carrying out a proper ecodesign before launching the product to market. This will allow reducing disassembling costs.

Wright et al. (2005) also measured the effect of improving the recyclability of a fibre optic cable by redesigning it. The authors modified some of the materials which compounded the cable in order to increasing their recyclability. In the redesign aluminium and organic gel were removed. The costs were joined according to the stages in the life cycle: PBT tube manufacturing, sheathing, stranding and LLDPE recycling, and divided by materials. In addition, LCAs were carried out in order to complete the analyses. Results showed that the largest contribution to costs in the cable system is from the material inputs. The fact of avoiding materials without compromising the function and security of the cable is translated in significant reduction in costs (up to 40%).

Replacing materials was the option selected by Ungureanu et al. (2007) in passenger cars, i.e. heavy material like steel was replaced by lighter aluminium. Different close-loop recycling percentages were assumed. Once the materials reached its end-of-life, it is supposed to be melted and sheet manufacturing ready to be used. Nevertheless, data regarding the kind of fuel used and its price were not shown. The authors composed a table in which the prices for both materials as scrap and recycled ones are presented. Based on that and taking into account only the recycling (post-use) stage, the calculations were easy and showed that, in this case, post-use was not considered significant for computing the total life-cycle cost. This is due to the high contributions of the manufacturing and use phases, especially as a result of the litres and gas price and the kilometres driven in the life of a car. Nevertheless, the premanufacturing costs depend greatly on the percentage of recycled material. The more recycled material, the less costs. Comparing the price of recycled steel, one can state that steel is cheaper than aluminium, but here additional circumstances should be considered. The aluminium scrap is also more expensive than the one for steel and its lightness offset the costs during the car´s lifespan.

An example of the influence of the recovered material is found in Craighill & Powell (1995). When comparing the recycling cost with the waste disposal cost of the selected materials, the net benefits were favourable to recycling except in the cases of plastics. According to the authors, this fact is due to the higher volume to weight ratio. In other words, one tonne of plastics occupies more volume than one tonne of glass, metals, paper, etc. As a result, this point explains a greater number of kilometres travelled per tonne of material, and thus, it results in negative net benefits. Derived from this observation, the importance of plastic collection trucks with integrated compactors is highlighted in order to favour recycling.

4.2.3 Economic evaluation and other techniques

LCC, as a decision tool, provides more information if it is presented with an environmental analysis (LCA), constituting the ecoeficiency. Furthermore, the combination of economic, environmental and societal analyses provides what is considered to be the sustainability.

Norris (2000) indicated the impossibility of separating the environmental study of a product from the economical one. Both should be studied in parallel since a separation of LCA and LCC does not allow characterizing completely the important relationships and trade-offs of alternative product scenarios. Moreover, the sum LCA plus LCC permits to know which modifiable stage provides the greatest combined economic and environmental leverage. Related with the previous point, taking into account the double-approach enables to determine the incremental costs of environmental improvement for diverse options, i.e. when comparing economic behaviour of recycling and landfilling.

In Kim et al. (2009) the recycling potential of electrical appliances components was calculated, i.e. in waste television, washing machines, refrigerators and air conditioners. Basically, the considered formula consisted in multiplying the economic score by a weighting value and the environmental score by another weighting value. The environmental weighting was used in order to reduce the number of decision variables into a manageable amount and to better communicate results from environmental studies. The weighting values derived from an analytical hierarchy process (AHP) method. On the one hand, the AHP reduces decisions to one-on-one comparisons and synthesizes the results. The weighting factors are determined based upon multiple factors obtained by interviews. On the other hand, subjectivity represents the main problem in this method. One way to solve this problem is questioning high-prepared people. Thus, relevant personnel in the industry and academia were interviewed. Results from questionnaires showed that the economic value is more important than the environmental value by three. As a result, the economic value was 0.75 and the environmental was selected as 0.25. The economic value was calculated taking into account the collection fee received from the generators, the disassembly cost, the maintenance cost, the residue disposal cost and the selling price of the recycled materials. After calculating the economic and the environmental value of each material and the weighting factors, the recycling potential was worked out. As it comes to economy, recycled copper showed the highest value due to its selling price, followed by steel, glass and circuit board, aluminium and plastic.

The ecoefficiency of a motor and this motor with a frequency converter were measured in Lyrstedt (2005). The formula of the ecoefficiency proposed was 1-(EDC[7]/LCC). On the one hand, EDC is based on the indicators measured in a LCA: greenhouse gases, acidifying gases, ozone depletion gases, gases contributing to creation of ground level ozone, emissions contributing to oxygen deficiency in water and consumption of non-renewable energy reserves. On the other hand, ECD and LCC functional units and system boundaries, in manufacturing, usage and disposal phase, were consciously selected equal since it allows comparing figures, and thus maintained the formula coherence. Scrap materials prices were negative inputs since the prices of selling the metal components are incomes, recycler pay you in order to obtain raw material.

Similar than in Lyrstedt (2005), in Lightart & Ansems (2007), shadow costs[8] were followed by considering the shadow price per environmental effect category under the CML2 LCA method (see Table 4). There the shadow prices were expressed in price per unit of emission reduction for the most expensive measure to be introduced to achieve an objective. The shadow costs were calculated by multiplying the quantity of equivalents by environmental category found in a previous environmental analysis by the shadow prices.

Effect category	Unit	Shadow price (€/kg eq.)
Abiotic mineral resources depletion potential	Sb eq	0
Acidification potential	SO_2 eq	4
Eutrophication potential	PO_4^{3-} eq	9
Fresh water aquatic eco-toxicity potential	1.4-DCB eq	0.04
Global warming potential	CO_2 eq	0.05
Human toxicity potential	1.4-DCB eq	0.08
Marine aquatic eco-toxicity potential	1.4-DCB eq	0.0001
Ozone depletion potential	CFC11 eq	30
Photochemical ozone creation potential	C_2H_2 eq	2
Terrestrial eco-toxicity potential	1.4-DCB eq	1.3

Table 4. Shadow prices per environmental effect category. Source: Lightart & Ansems (2007).

[7] EDC: Enviromental damage costs
[8] The shadow cost of a resource is the additional profit generated by that resource and it usually has important environmental impacts. It expresses the environmental burden of a product or other system in a monetary unit.

Although 1,000 disposable polystyrene cups recycling showed a shadow cost of -0.29 €, it should be stated the fact that recycling a material do not necessarily involves negative shadow costs. In the same study, 1,000 disposable paper cups recycling were equivalent to 0.09 €. These points are explained by paper cups were composed by paper and coated with polyethylene. Recycling paper cups had environmental impacts when recycling, but recycling polystyrene cups offered a net negative impact in some environmental categories. The negative shadow costs of these categories counteracted the positive ones of the other and, as a results, the net shadow cost appeared negative.

In regards with sustainability, environmental concern has made people to prefer recycling to other EOL alternatives like landfilling or incineration. A clear economic impact due to social behaviour is the choice of a social discount rate. The social discounting rate is related to the ethic of intergenerational equity and is influenced by country, standard of living, purchasing power... It is possible that most people do not willing to pay extra money for recycling, but for obtaining some benefits not necessarily economic ones. These are basically subjective and difficult to measure. The willingness to pay concept is applied to recycling when citizens are asked to pay extra money to use recycled containers. As an example we should not forget that the first stage in the recycling process is to collect recyclable materials. Few studies have been carried out in relation with this issue. One of them (Gillespie & Bennett, 2011) determined the willingness to pay for the recycling collection service. Inhabitants from Brisbane, Australia, were asked about the possibility and frequency of establishing a recycling service collection scheme through questionnaires. Figures showed that people was able to pay 131.49 Australian dollars (A$) per year for a fortnightly recycling service and an extra 18.30 A$ to increase the frequency of this service to weekly. However, on average, respondents declined by 34.18 A$ per year if general waste collection increases from weekly to twice a week. In other words, they did not want to pay more for duplicating the general waste collection. This is a clear indicator on how environmentally concerned people can push to what they consider as more beneficial in environmental, social and economic approaches.

4.2.4 Methodological problems of LCC

The used of technical tools usually implies some points that must be considered. Regarding the main difficulties, three concepts should be explained: Types of LCCs, discounting and uncertainty of results.

4.2.4.1 Types of LCCs

Not all the case studies on LCC correspond to environmental LCC. In some cases, authors have chosen different kinds of economic analysis in order to consider further approaches. For instance, Utme (2009) proposed a non-conventional LCC. Based on literature, she modelled the LCC as a sum of capital costs, costs produced in the operational phase, costs resulted from occupational accidents and fatalities, environmental expenditures and decommissioning costs in fishing fleet. The fact of including costs like the ones derived from accidents and fatalities is an indicator of a societal LCC. It is relatively easy to adapt this approach to the recycling process. Capital costs, costs produced in the operational stage (recycling), costs derived from occupational accidents and fatalities are produced during the process, the last with a small probability. In addition, environmental expenditures could materialise in the near future, for instance with the adoption of a green tax based on the CO2 emissions. Decommissioning costs could be assimilated to transport of recycled material.

A different approach was followed by Dahlbo et al. (2007) in which costs were calculated through a societal life cycle costs (SLCC) and environmental impacts were measured by LCAs. SLCC refers to the costs produced in the entire life cycle of a product or service within the system boundaries defined in the LCA. Similarly as before, this approach considers both the direct costs (labour, energy, etc.) and the shadow costs, but taking into account also social issues. The fact of defining the costs from a social point of view instead of an agent one implies, for instance, that taxes levied on stakeholders and obtained by society are cancelled out when summing the costs. Thus, the difficulties of measuring the social costs are highlighted and rarely find in literature due to subjective perception of impacts and its economisation vary from country to country and from one year to other.

4.2.4.2 Discounting

When carrying out a LCC on a recycling facility another problem appears: to consider changes in costs through time. For overcoming it, the time value money expressed as discounting is used. It considers inflation, cost of capital, investment opportunities and personal consumption preferences. Actually, here we have also uncertainties because of nobody knows exactly what value will have inflation for instance in five years' time.

There are two types of discounting:

- The one used in the global LCC
- The discounted cash flow of the monetary flows which take part in product life cycles

In economic studies which consider medium and long run, the discounting process must be taken into account as discounted cash flow. It means, expressing the value of a future cost item in today´s monetary terms. Logically, products which are consumed in the short time like most of the packaging do not need to consider the discounted cash flow, but recycling facilities works for years and waste flow also vary in time. One can state that higher yield of a recycling facility as a result of increment in waste production or technological advance makes it possible. Because these present values are not unique in the sense that the choice of discount rate affects the outcome, a sensitivity analysis must be conducted to find out how crucially the choice of the discount rate affects the costs (SETAC, 2008).

In addition, discounting in the global LCC varies and should follow different rules depending on the kind of LCC (SETAC, 2008):

- Conventional LCC: It is recommended, although usually not applied
- Environmental LCC: Discounting of the total LCC result is not applied, although use of discounted cash flows for money flows occurring at different times within 1 product life cycle (usually for periods no longer than 5 to 15 years) is commonly applied and does not violate the steady-state assumption. Use of discounted cash flows shall be considered as function of the goal and scope and time duration of a product life cycle

- Societal LCC: Determination of an appropriate discount rate for societal LCC is iterative and requires a sensitivity analysis. Is very complex and depends directly on the impact category and the product/process intended to be analysed

4.2.4.3 Uncertainty of results

Environmental LCC is influenced by uncertainties as a result of the way of ecological and social systems change in the future should be considered in studies, not to mention economic changes like the inflation. Issues not considered as problems today could be in the future. For instance, back in 1950 nobody feared DDT (dichlorodiphenyltrichloroethane), but it was banned for agricultural use in the USA in 1972. Imagine that a LCC on DTT was carried out and it was not considered all the impacts both on human life and nature. How much millions would it represent? How to measure it?

Moreover, a double counting could be produced if considering this approach. Environmental costs could be partially internalised through policy efforts aim at reducing these costs like air pollution controls, and environmental policies focus on restructure economic practices towards long-term sustainability. Furthermore, price volatility[9] was pointed out as a parameter which could affect the recycling markets. Indeed, uncertainty itself is a common driver of price volatility (Stromberg, 2004).

Under the current situation, price volatility has become extremely important (see section 2) and its influence on material recycling prices is expected to decrease as soon as decisive issues will be slowed down, especially as it comes to Asian demand as well as the international crisis.

5. Conclusion

Recycling entails different environmental benefits like energy savings, natural resources conservation and reduction of waste disposal to landfill. Nevertheless, in order to determine which end of life option is also efficient, not only from an environmental point of view but also from an economic point of view, an economic analysis should be carried out.

It is necessary to assure the Ecoefficiency (environmental and economic analysis) of the recycling process selected and it is also important to consider the different market studies available, since effectiveness of recycling can be influenced by market conditions. It has been stated the influence of living in a globalized world, in which the price of recycled materials in Europe is strongly distorted by geopolitical issues in the distant Asia or in the oil producer countries. The high demand of different recovered materials by the Asiatic southwest has made prices to be increased in the last years. Furthermore, differences in prices of machinery, production and labour costs between countries compel the final price of recycled materials. Moreover, uncertainties due to the crisis have made prices to appear like a saw, and especially the effect on the great price fallings in 2008. As it comes to oil price, it influences indirectly the recycling price of plastics since it modifies the virgin material cost and, as a result, makes one of them more economically attractive. It should be

[9] Price volatility is a measure of the variation of a financial instrument (recycled materials prices in this case) over the time.

remembered that the main competitors of recycled materials are the virgin ones, and economic and environmental issues constitute the main drivers to select one of them. Thus, it is necessary to consider the recycled materials market as a whole by taking into account information from both, the regional and international perspectives. Market studies make it easy to decide whether selling a product in one or another country is better or not, and even to consider recycling as the best end of life option.

Recycling starts at the collection stage and together with transport and sorting could affect seriously the final material price. In some cases these three stages can represent the highest economic impact on recycling. A good sorting will allow increasing the recycling yield. Governments have pushed inhabitants to adopt this sub-stage at household in order to facilitate waste collection. Then, a shredding is necessary to increase the efficiency of the next stage: the recycling itself. Nevertheless, when it comes to paper and wood, shredding damages fibres and is not advised. The combination of the different steps as well as the recycling process depends greatly on the material and on its physicochemical characteristics. Specific sub-stages can be observed in the treatment of only some materials. For instance, melting is required in plastics, metal and glass recycling, whereas it is substituted by pulping in paper and board.

The economic and environmental efficiency of a recycling process is highly subjected to a series of aspects not directly related to the recycling process itself but to other aspects such as transport conditions, collection practices or the availability and the final price of the final recycled material. As a result, a non-careful study of those aspects could lead to situations where the benefits of recycling may be overshadowed by the economic and environmental impacts of the previous or posterior recycling stages.

Ecodesign comprises both improving the design for disassembling and selecting the best materials. Examples of how design for disassembling improves the recyclability have been shown and its relation with the disassembling cost in multimaterial products. It is of great interest to facilitate this point since it contributes to reduce the economic impact of this sub-stage. The selection of materials is also another way of improving the ecodesign and can constitute an advantage from the economic perspective, due to environmentally friendly waste might have a better purchasing cost over the most damaging ones. By using ecodesign, apparently trivial issues can be detected as important contributors to recycling cost. For example, it has been stated the fact that plastics usually represent less weight than glass or metals in a determined volume. But considering plastic collection in which trucks are driving and the associated costs, i.e. fuel consumption and driver salary, it is clear that the selection of materials constitutes an important point from the EOL perspective.

The combination of the environmental LCC and the LCA studies (ecoefficiency) make up a dynamic tool capable of defining the most environmentally and economically important of the recycling process. There are three types of LCCs: conventional, environmental and societal, which compose different approaches to the economic analyses and are used as tool in order to select the best alternative in EOLs and recycling processes. Since there are various types of LCCs, it should not confuse the costs and boundaries included in the economic studies. It has been stated that the environmental LCC is the approach which offers a better understanding since is similar to the LCA but in economic terms and considering both, the internal and the external costs. Environmental LCC share similar requirements with LCA like the functional unit and system boundaries. Thus, they allow obtaining a complete analysis of the recycling process from an economic and environmental point of view. However, it should be remarked that in addition to the LCA and LCC analysis, market studies are strongly recommended to assure that market conditions will not hamper or influence negatively the general efficiency and effectiveness of recycling.

The use of LCC encompasses methodological problems. On the one hand, discounting rates should be taken into account when working out an economic study on a recycling facility because of its long life span. This fact is not considered in short-life products like most of packaging. On the other hand, uncertainty due to lack of data constitutes a weak point. Such deficiency could be solved in case information is found in literature or through interviews to experts or stakeholders like in the SLCC. Nevertheless, it cannot be obtained in some cases like when deciding the inflation in the coming years.

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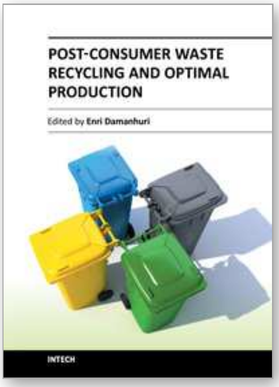

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This book deals with several aspects of waste material recycling. It is divided into three sections. The first section explains the roles of stakeholders, both informal and formal sectors, in post-consumer waste activities. It also discusses waste collection programs for recycling. The second section discusses the analysis tools for recycling system. The third section focuses on the recycling process and optimal production. I hope that this book will convey both the need and means for recycling and resource conservation activities to a wide readership, at both academician and professional level, and contribute to the creation of a sound material-cycle society.