Sorting of co-mingled light packaging waste to maximise recycling yields for high-quality output

In a nutshell

Summary overview
When light packaging waste (i.e. packaging made of plastics, composites, aluminium and steel, sometimes also including fibres (paper and cardboard)) is collected together (co-mingled), it is best practice to implement advanced sorting of the co-mingled packaging waste in materials recovery facilities (MRF). A typical state-of-the-art plant has five main technical sections: • Feeding and preconditioning: this includes opening bags and feeding a constant flow of input material. • Pre-sorting: this involves removing unsuitable items. • Sorting: this includes several steps, e.g. separating fibre from containers; sorting fibre; sorting metal containers by using magnets, eddy currents or X-ray; first sorting of plastic containers by polymer (e.g. separation of PET bottles from other plastic containers). • Refining: this consists of additional sorting steps, such as further sorting of polymers by type (e.g. HDPE, PP) and colour in order for the material output quality to meet market requirements. Quality control is performed by automatic or manual sorting. • Product handling: this section consists of the baling processes and product storage as bales, loose material or in containers; product handling can also include loading operations for further downstream processes. As MRFs tend to receive and sort materials from different local collection schemes, with varying compositions, a state-of-the-art MRF must have the flexibility to efficiently accommodate these variations.

Waste management area							
Cross-cutting	MSW - strategy	MSW - prevention	MSW - collection	MSW - EPR	**MSW - treatment**	CDW	HCW

Applicability
In principle, there are no barriers to building and operating a packaging waste sorting plant. However, careful planning (especially considering the collection schemes in place, the plant capacity and the availability of markets for the sorted materials) is required as part of an integrated waste management concept. An important factor that needs to be determined is the optimal plant capacity. Finally, the impurity rates of co-mingled light packaging waste delivered to the plant affect its operations, performance (e.g. plant sorting rate) and economics (e.g. processing costs, revenues from recyclable fractions).

Specific environmental performance indicators

- Plant sorting rate (weight %), calculated as the annual quantity of materials sent for recycling divided by the annual quantity of co-mingled packaging waste processed.

- Energy efficiency (kJ/t), calculated as the annual total energy consumption of the plant divided by the quantity of co-mingled packaging waste processed.

- GHG emissions (t CO_2e/t), calculated as the annual total CO_2 equivalent emissions (Scope 1 and 2) of the plant divided by the quantity of co-mingled packaging waste processed.

Benchmark of excellence

Material recovery facilities sorting co-mingled light packaging waste have a plant sorting rate of at least 88 %.

Description

In many parts of Europe, packaging waste (i.e. packaging made of plastic, composites, aluminium and steel, sometimes also including paper and cardboard) is collected together in order to ease the waste separation task for consumers and to reduce collection costs.

When that is the case, in order to enable a high level of recycling, an advanced sorting of the co-mingled packaging waste in a material recovery facility (MRF) can be considered best practice. This BEMP deals with the sorting of co-mingled recyclables, including or excluding paper/cardboard. A number of technologies (e.g. NIR (near-infrared), multi-sensor systems, ultrasonic or VIS-camera, magnetic and/or air separation) are used for sorting and achieving the high level of segregation that allows recycling of a very high share of the mixed packaging waste collected from households.

There is a large variation in MRF plant design and process configurations owing to regional differences such as inflowing waste compositions, plant size, availability and cost of manual labour and regulatory frameworks. Moreover, relevant differences exist based on the inclusion or exclusion of fibres (paper and cardboard) and the types of plastics managed. In general, it is observed that large plants with treatment capacities of more than 75 000 t/year are the best performing ones, as they reach the economies of scale needed for investing in the most advanced sorting technologies (Cimpan et al., 2015, 2016; WRAP, 2007).

Despite the significantly different process layouts, different sections or modules in the plants, that have a standard main function, can be identified (Cimpan et al., 2016; WRAP, 2006). On the basis of this main function, five main technical sections can be identified in a typical state-of-the-art plant:

- *Feeding and preconditioning*: this section consists of reception (unloading) and storage of input materials and input feeding and preconditioning processes, such as bag opening and metering the flow of materials. The objective of this stage is to open and empty bags, loosen up recyclables and produce a constant and even flow of material into the process.

- *Pre-sorting*: this section consists of removing those products not intended for recycling, such us oversized items, unrecyclable contaminants, recyclable materials which the sorting system is not designed to segregate, or other items that might otherwise hinder sorting activities downstream, such as plastic film or oversized cardboard.

- *Sorting*: this section consists of primary sorting processes, which first separate the material flow per groups or types (two-dimensional fibre streams from three-dimensional container streams), followed by advanced sorting steps that continue the sorting process by further size segregation, isolating in each flow the different valuable fractions (paper by fibre grade, containers by material type, etc.).

  Typical sorting steps and related equipment are (WRAP, 2006; WRAP, 2007; Titech, 2011):

  - separating fibre streams (i.e. paper, card, cardboard) from container streams (i.e. cans, plastic bottles and other containers, etc.) using disc screens or trommel screens;

- sorting fibre into its various grades (old corrugated cardboard, newspapers and magazines, mixed papers) using disc screens or more advanced optical scanners (NIR (near-infrared) sensors);
- sorting metal containers using magnets for sorting steel or eddy current separators for sorting aluminium or X-ray sorting technologies to distinguish metals based on their density;
- sorting plastic containers into a wider range of polymers (typically HDPE and PET) using optical scanners (NIR sensors).

- *Refining*: this section consists of additional sorting steps, such as sorting polymers by type (e.g. PP, LDPE) and colour using optical sensors (VIS-camera, NIR sensors), which aim to bring the material output quality to market requirements. Quality control is performed by automatic or manual sorting.
- *Product handling*: this section consists of the baling processes and product storage as bales, loose material (sorting residues) or in containers (metals). This section includes loading operations for products and residue streams to be delivered to downstream processes.

A detailed description of the plant design and process configuration in the most advanced and efficient sorting plants, is provided in the operational data section of this best practice.

As MRFs tend to receive and sort materials from a variety of different local collection programmes, which can collect different materials or the same materials in a different manner, a state-of-the-art MRF must have sufficient flexibility to efficiently accommodate these variations. This can be achieved by having adequate in-feed lines, i.e. different points in the overall sorting process where various materials may enter the system. This avoids the costs of passing the materials already sorted prior to delivery to the MRF through unnecessary sorting stations (WRAP, 2006). The plant flexibility is also important because the composition of collected co-mingled packaging waste is continuously changing due to evolving production and consumption patterns (e.g. reduction of paper use), new material use (e.g. bio-plastics) and even changes in regulation frameworks (addition of new materials or products admitted in the co-mingled streams), which also requires continuous development in sorting technologies.

Environmental benefits

The sorting of co-mingled packaging enables the recycling of plastic, paper/cardboard, ferrous metals and non-ferrous metals. Thus, the material cycle can be closed, with significant savings in terms of primary raw materials and energy consumption and CO_2 emissions.

There is a lot of literature about the evaluation of the environmental benefits of recycling, mainly based on the application of LCA methods (Hogg D. et al., 2015; Bianchi D., 2012), but there is a lack of comprehensive studies focused only on the environmental benefits of material recovery facilities, considering the different types of existing MRFs and comparing their environmental benefits with those of other treatment alternatives.

Some scientific and grey literature exist related to the analysis of specific case studies with an LCA approach (Palm D., 2009; Carré A., 2015; Krones J. et al., 2012), and a more comprehensive study, although focused only on Portugal, Belgium and Italy (Lombardy), was developed by the European Investment Bank (2014) as part of the EIMPack – Economic Impact of the Packaging and Packaging Waste Directive. In order to provide some figures about the environmental benefits of this best practice, below the results observed in this last reference study are described.

The LCA methodology applied in the European Investment Bank study was developed according to the ISO 14040:2006 requirements and was carried out focusing on the end-of-life of packaging, considering within the system boundaries waste packaging collection, sorting in MRFs, transport of waste to recyclers, the recycling process itself and the savings in terms of consumption of energy and raw materials from the recycling process (expanded boundaries). The functional unit of the LCA study is one tonne of municipal packaging waste managed by each Green Dot Company (i.e. SPV, Portugal; Fost Plus, Belgium; and Conai, Italy) in the year 2010. The assumptions adopted include the following aspects:

- The secondary materials produced through the recycling of packaging waste replace the corresponding primary materials (i.e. those produced from virgin raw materials), assuming a substitution ratio of 1:1 for all packaging materials except paper and cardboard packaging, for which a substitution ratio of 1:0.83 was assumed, because the paper fibres degrade in the recycling process, so they cannot be reused indefinitely. The savings in energy, raw materials and emissions released from the avoided production were considered in the recycling process.

- The electricity produced from the landfill gas (LFG) for the Portuguese case and from the waste incineration for the three case studies is supposed to substitute the same amount of electricity produced in each country (considering the different energy sources). This energy corresponds to the real energy mix production in 2010 (average approach).
- The sorting processes were modelled considering the main collection and sorting schemes in place in the different countries. In Portugal, the sorting processes were modelled for paper/cardboard, plastic, metal and drink packaging. For glass packaging, only separation efficiency was taken into account. In Belgium, the sorting process was only considered for the mixed flow (plastic, metal and drink packaging) since paper/cardboard and glass packaging waste is sent directly to the recyclers/reprocessors. In Italy, only the sorting of ferrous metals and the separation of the multi-material fraction were modelled. The sorting processes were modelled based on the main consumption levels (electricity, diesel, etc.) related to the operation and considering the rejected material (quantities and final disposal).

In the study, besides the CO_2 emissions (Climate change indicator), other impact categories of the LCA method were considered: Photochemical oxidant formation, Eutrophication, Human toxicity and Acidification. Two different scenarios were analysed and compared:

- The real scenario in 2010 (hereinafter called “Recycling scenario”), where packaging waste was selectively collected, sorted and sent for recycling (i.e. in this scenario, they considered the 2010 recycling level in each country).
- A hypothetical scenario (hereinafter called “Non-Recycling scenario”), where packaging waste would be collected as residual waste (in the refuse collection circuit) and sent for incineration and/or landfill. Note that in Belgium and Italy (more specifically the region of Lombardy) only incineration was considered in this alternative scenario.

The total environmental impacts resulting from each scenario for the three countries are shown in Table 1. As expected, the current “Recycling scenario” proved to be more environmentally friendly than the “Non-Recycling scenario” for the three case studies. Regarding the GHG emissions, in 2010, the “Recycling scenario” saved between 14.3 Mt/year of CO_2e in Portugal, 516 Mt/year in Belgium and 643 Mt/year in Lombardy. It should be noted that in Lombardy the “Non-Recycling scenario” showed good results for the environment in contrast to the other two countries due to the incineration process with energy recovery. The large difference observed between Portugal and the two other countries was due to the recycling of paper/cardboard. In Portugal, the primary pulp production (replaced by the recycling fibres) generates electricity from by-products (biomass, black liquor, etc.) of the process. The pulp and paper production is self-sustainable in terms of energy with a surplus that is introduced into the National Grid. This surplus of electricity is accounted for as a benefit lost with recycling since this activity only consumes energy. In Belgium and Italy, the primary pulp is imported and information about the quantity of electricity generated during the pulp production process is not available. The pulp production process figures existing in the Ecoinvent 2.2 database of SimaPro was assumed as the avoided product in the paper/cardboard recycling process. The surplus of electricity generated in the avoided product was excluded as a simplification of the problem.

Table 1. Total environmental impacts of each scenario for the three case studies, considering the LCIA methods used for the Eco-costs 2012 valuation[1]

Impact category	Unit	Portugal	Belgium	Italy (Lombardia region)
Recycling scenario				
Climate change	kg CO_2e	-1.43E+07	-5.16E+08	-6.43E+08
Human toxicity	CTUh	-2.10E-01	-1.05E+01	9.53E+01

Impact category	Unit	Portugal	Belgium	Italy (Lombardia region)
Photochemical oxidant formation	kg NMVOC	-4.07E+05	-2.82E+06	-4.25E+05
Eutrophication	kg Peq	-4.91E+03	-7.12E+04	-3.59E+05
Acidification	kg SO_2e	-1.11E+06	-4.57E+06	-3.23E+06
Non-Recycling scenario				
Climate change	kg CO_2e	7.46E+08	8.35E+08	-2.38E+08
Human toxicity	CTUh	1.04E+00	3.93E+00	3.73E+01
Photochemical oxidant formation	kg NMVOC	1.84E+05	3.39E+05	-2.11E+05
Eutrophication	kg Peq	3.72E+04	6.55E+02	-1.77E+05
Acidification	kg SO_2e	1.13E+05	1.60E+05	-1.65E+06

Source: European Investment Bank, 2014

[1] The study use different Life Cycle Impact Assessment (LCIA) techniques and different weighting sets for the several environmental impact categories analysed which has an important impact on the overall results. Here we only refer to the results obtained applying the Eco-costs2012 method.

Side effects

As stated in the previous section, the operation of the MRFs is associated with energy consumption. Reference figures for this impact category are provided in the article by Cimpan et al. (2016) who developed a model simulating the technical and economic performance for MRFs sorting lightweight packaging waste, i.e. a material mixture with a high content of plastics (around 50 %) consisting of a mix of different packaging polymers, ferrous and non-ferrous metals, a paper and cardboard packaging fraction, beverage cartons and other composite packaging. Four different plants were modelled in the study, as shown in table 4, reflecting clearly the MRFs operating in Germany but representative also of the plant operating conditions in other EU countries.

Table 4. Main MRF process parameters for the plants modelled in the reference study

Specification	Basic	Medium	Medium plus	Advanced
Planned processing capacity (t/year)	25 000	50 000	75 000	100 000

Specification	Basic	Medium	Medium plus	Advanced
Working days (days/year)	250	250	250	250
Shifts and hours per shift (shift/day; hours/shift)	2;8	2;8	3;8	3;8
Operational hours (hours/year)	4 000	4 000	6 000	6 000
Plastic sorting – products	Plastic film, Mixed hard plastics	Plastic film, PE, PP, PET	Plastic film, PE, PP, PET, PS	Plastic film, PE, PP, PET, PS, PET bottles
Processing technology	Only essential material conditioning steps (sieving and air classification), heavily reliant on manual sorting	Comprehensive conditioning (several sieving steps, air classification and ballistic separation), both automatic and manual sorting, mostly manual product quality control	Almost identical to the medium plant with more extensive plastic sorting	State-of-the-art process design and technology, almost entirely based on automatic sorting, both automatic and manual product quality control

Source: Cimpan C. et al., 2016

Modelling results indicate that the average consumption of electricity to process one tonne of lightweight packaging waste amounts to about 100 kWh and more than two thirds of this amount is connected to sorting and refining steps. The estimated consumption levels for the four MRF types, in the different processing steps, are shown in Table 5.

Table 5. Yearly total and specific (per tonne) consumption of electricity and diesel for the plants modelled in the reference study

	Basic		Medium		Medium plus		Advanced	
	Electr. (MWh)	**Diesel** (10^3 L)	**Electr.** (MWh)	**Diesel** (10^3 L)	**Electr.** (MWh)	**Diesel** (10^3 L)	**Electr.** (MWh)	**Diesel** (10^3 L)
Per tonne input	**102.4 (kWh)**	**3.7 (L)**	**89.8 (kWh)**	**2.2 (L)**	**91.3 (kWh)**	**2.2 (L)**	**96.5 (kWh)**	**2.2 (L)**
Total per year	**2 560**	**91.9**	**4 488**	**110.3**	**6 847**	**165.4**	**9 649**	**222.7**
Feeding and preconditioning	95	35.4	206	42.4	309	63.6	1013	106.0
Conditioning	201	0	389	0	585	0	790	0
Sorting	924	0	1 319	0	2 094	0	2 794	0
Refining	874	0	1 950	0	2 925	0	3 383	0
Product handling	217	56.6	289	67.9	435	101.8	863	116.7
Unassigned	250	0	333	0	499	0	807	0

Source: Cimpan C. et al., 2016

The lowest specific consumption levels are observed in the “medium” plant, while they increase in the “medium plus” and “advanced” configurations as one of the processes that contributes most to electricity consumption is the production of compressed air for the NIR sorters, which are especially large for the “advanced” plant. A consumption level of around 3 L of diesel per tonne of input waste is also identified in connection with mobile equipment in the plants, i.e. the equipment used to move waste on the tipping floor and bales of recovered material (e.g. front-end loaders, forklifts, polyp excavators). Diesel consumption levels are a bit higher (3.7 L/t) in the “basic” plant than in the more automated ones (2.2 L/t).

Besides energy consumption, emissions of dust and odour can also occur but do not appear to be significant for MRFs, as only dry recyclables are sorted in these facilities. In any case, adequate emission abatement technologies must be considered given the potential presence of biowaste residues or dusty materials. Drainage infrastructure of the tipping floor and storage areas and adequate treatment of the collected waste water must also be foreseen. The safety and health of workers performing manual sorting have to be assured, with special regard to their exposure against airborne fungi, bacteria and other biological agents.

Applicability

In principle, there are no barriers to building and operating a packaging waste sorting plant. However, careful planning (especially considering the collection schemes in place in the surrounding area, the plant capacity and the availability of markets for sorted materials) is required as part of an integrated waste management concept, including awareness-raising and information campaigns for citizens and efficient waste collection.

In this respect, an important issue that needs to be considered is related to the optimal plant capacity. This factor affects the overall MRF efficiency, as well as the specific processing costs (as explained in the Economics section), and must be carefully considered case by case, given the region/site-specific framework conditions. The following needs have to be considered in particular:

- the transport distances from collection areas to the sorting facilities: this would suggest keeping the treatment capacity low so that the facility serves a relatively small geographical area, thus allowing collection vehicles easy access to unload their materials during collection rounds;

- the economies of scale: this, on the other hand, would suggest keeping the treatment capacity high, so that investments in advanced sorting technologies are more feasible and allow the achievement of higher recovery rates with lower specific processing costs (EUR/t of input waste);
- the availability of manual labour or the will to create local jobs: this would influence the choice of manual versus automated sorting (i.e. low-capacity versus high-capacity plants respectively), although it should also be considered that manual sorting jobs imply difficult working conditions (noise, risk of injuries and infections, ergonomy);
- the need to avoid plants operating in overload capacity conditions: this would significantly reduce the sorting efficiency and increase the specific processing costs.

Economics

The economics of the different sorting systems vary widely depending on system specifics, such as location, size, whether they serve urban or rural communities and many other factors (Cimpan C. et al., 2015). Based on the available scientific and grey literature (ADEME, 2013; Cimpan C. et al., 2016; WRAP, 2007), an overview of the costs associated with co-mingled waste packaging sorting in MRFs is provided below, focusing in particular on the economy of scale benefits.

A study from ADEME (2013) shows that the average sorting cost in the MRFs operating in France, based on the costs observed in 112 sites, is EUR 163/t, with a high dispersion of values, ranging between EUR 100/t and EUR 220/t. Analysis of changes in sorting costs shows that many elements simultaneously influence such variations. The region where the MRF is located appears to be an important factor, related to the level of urbanisation and the resulting land pressure, with higher costs in the most urbanised regions. The collection scheme is also a factor influencing the sorting cost, which is lower for double-stream than single stream collections. The increase in the reject rate also appears to be correlated with the increase in the cost of sorting, while the simultaneous treatment in the same plant of municipal and commercial waste appears to be correlated with a decrease in the cost of sorting.

Valuable reference figures as to the economies of scale are provided by Cimpan C. et al. (2016), who evaluated the economic performance for MRFs sorting lightweight packaging (LWP) waste by modelling four plants of progressively higher capacity and technological level, as described above in Table 4. The method used was budget-based economic analysis, whereby only direct financial costs and benefits were counted. The analysis precludes taxes, subsidies and revenues from gate fees (based on contracts with Dual Systems Deutschland Gmbh). The cost categories included were: (1) specific processing costs (these relate only to the facility); (2) costs of output management (revenues/disposal cost); and (3) transfer and long-distance transport for the supply of LWP. The results obtained for the four MRFs modelled are shown in Table 9, Figure 3, 4 and 5.

Table 9. Model results: total capital and operational costs

Specification	Basic	Medium	Medium plus	Advanced
Capital investment				
Construction/building costs (EUR)	2 947 000	4 785 000	4 863 000	6 843 000
Processing equipment (EUR)	3 153 000	6 634 000	6 987 000	12 616 000
Mobile equipment (EUR)	638 000	693 000	693 000	1 067 000
Project costs (EUR)	203 000	364 000	377 000	616 000
Total capital investment (EUR)	**6 939 000**	**12 475 000**	**12 919 000**	**21 141 000**
Annualised capital expenditure (Capex)				
Construction/building costs (EUR/year)	237 000	384 000	391 000	550 000
Processing equipment (EUR/year)	409 000	860 000	1 074 000	1 681 000
Mobile equipment (EUR/year)	148 000	161 000	161 000	247 000
Project costs (EUR/year))	17 000	30 000	31 000	50 000
Total Capex (EUR/year)	**809 000**	**1 433 000**	**1 654 000**	**2 526 000**
Operational expenditure (Opex)				
Costs for repairs/maintenance (EUR/year)	138 000	236 000	245 000	392 000
Costs for resource consumption (EUR/year)	525 000	856 000	1 303 000	1 810 000
Costs for personnel (EUR/year)	1 297 000	1 838 000	2 732 000	2 379 000
Insurance (EUR/year)	43 000	78 000	80 000	120 000
Total Opex (EUR/year)	**2 003 000**	**3 006 000**	**4 358 000**	**4 700 000**
Capex + Opex	**2 815 000**	**4 439 000**	**6 012 000**	**7 226 000**

Source: Cimpan C. et al., 2016

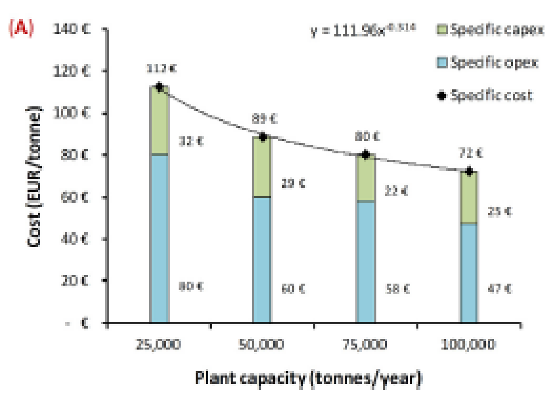

Figure 3. Specific processing costs, excluding costs for LWP waste supply and output management

Source: Cimpan et al., 2016

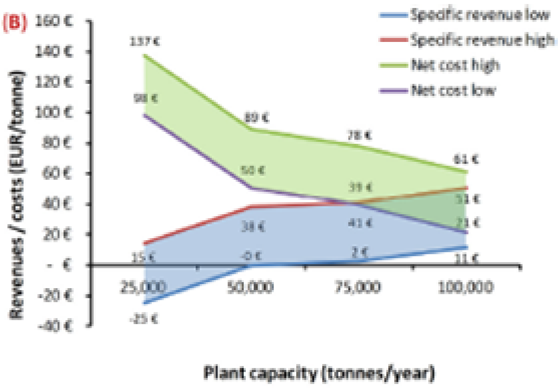

Figure 4. Net processing costs (Specific processing costs - costs of output management), considering low and high revenue values

Source: Cimpan C. et al., 2016

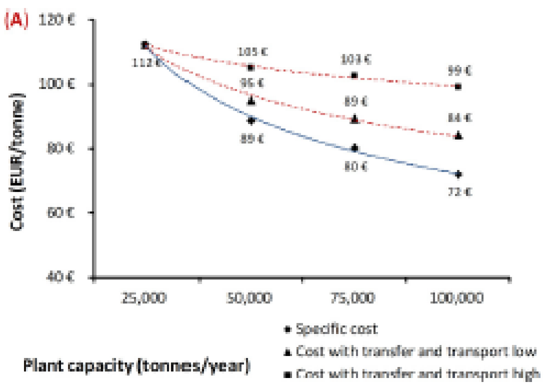

Figure 5. Specific processing costs with the addition of transfer and long-distance transport

Source: Cimpan C. et al., 2016

The results for specific processing costs illustrated in Figure 4 suggest that economy of scale effects do materialise in LWP MRFs, as shown by the cost of sorting one tonne of LWP which decreases from EUR 110 in the small-capacity basic plant to EUR 70 in the large-capacity advanced plant.

The effect on the specific processing costs of the revenues from material sales and disposal costs (costs of operational management) is illustrated in Figure 5. The analysis was carried out considering the range of market prices and waste disposal costs reported in Table 10 for each plant output. The lower/blue band in Figure 5 illustrates the interval of variation for costs/benefits pertaining to output management, with the lower and higher border lines reflecting the low and high price levels. The higher/green band illustrates the interval of variation induced by the output management on the calculated net costs. The conclusion that can be drawn is that LWP MRFs always incur net costs when solely the income of material sales is considered. This net cost then has to be balanced by the income from gate fees.

Table 10. Market values assumed for the MRFs outputs.

Output	Low level prices (EUR/t)	High level prices (EUR/t)
Plastic foils > A4	50	150
Large plastic containers/HDPE coloured	190	240
Paper/Card and composites	30	60
Ferrous metals	140	175
Non-ferrous metals	300	470
Beverage cartons	0	0
PET bottles	120	180
Standard packaging polymers (PP, PE, PS, PET)	100	120
Mixed plastics	-30	0
Sorting residues	-90	-50

Source: Cimpan C. et al., 2016

The possible increase in specific processing costs considering additional costs of transfer and long-distance transport is illustrated in Figure 5. These cost items assume relevance in determining the plant capacity, as it is estimated that a catchment area with around 800 000 inhabitants is adequate to provide the LWP waste input for the basic plant, whereas for the advanced plant, a catchment area of over 3 million inhabitants is required. For high-capacity plants, this means that additional costs relating to transfer stations and long-distance transport become important factors in the economics of sorting. As in the case of output management costs, for the transfer and transport costs different cost ranges have also been considered in the study, as shown in Table 11. The new cost curves in Figure 5 still indicate economies of scale with increasing plant size, although these appear to become very small with the high cost for transfer. This result emphasises the importance of accounting for necessary transfer and transport when large plants are planned. Although costs related to these operations are not necessarily incurred by the sorting plants, they do contribute to the overall waste management system costs.

Table 11. Costs associated with LWP waste transfer and long distance transport

Specification	Basic	Medium	Medium plus	Advanced
Transfer cost low (EUR/year)	0	125 000	250 000	375 000
Transfer cost low (EUR/year)	0	625 000	1 250 000	1 875 000
Transport >25 000 and < 50 000 t/year (EUR/year)	0	190 972	190 972	190 972
Transport > 50 000 and < 75 000 t/year (EUR/year)	0	0	254 630	254 630
Transport > 50 000 and < 75 000 t/year (EUR/year)	0	0	0	381 944
Total cost increase low (EUR/t)	**0**	**6**	**9**	**12**
Total cost increase high (EUR/t)	**0**	**16**	**23**	**27**

Source: Cimpan C. et al., 2016

In brief, the analysis carried out by Cimpan C. et al. corroborated the fact that LWP MRFs operate at an overall net cost, which has to be covered by the gate fees or sorting fees under any plant configuration, as the revenues from sales of recovered materials cannot fully cover the processing costs. The analysis also showed that strong capacity-related economies of scale occur with regard to processing costs and that the practical optimal capacity level is achieved at around 50 000 t/year, while optimal process efficiency, measured as total material recovery, is realised in large plants with high degrees of automation (>75 000 t/year), but is in all cases significantly dependent on operational practice.

These main results are also confirmed by other reference studies. In particular, WRAP (2006, 2007) has developed a MRF cost model that provides representative capital and operating costs involved in setting up and operating a MRF. A sample cost curve for MRF operations in the case of a single-stream MRF is presented in Figure 6.

The curve shows the variation in the unit cost per tonne for MRFs of different design capacities. It shows that the unit cost per tonne begins to level out at higher throughput tonnages (80 000–100 000 t/year) but rises significantly at lower throughput tonnages. Besides the differences in the specific processing costs simulated in the previous study, due to the different assumptions in the cost models, this result confirms that economies of scale can be realised by processing more recyclables at larger MRFs. The WRAP MRF cost model suggests indeed that MRFs below an annual capacity of 80 000–100 000 t will not achieve optimal operating costs. Facilities of this scale are needed to achieve economies of scale but also to justify investment in more automated and sophisticated sorting equipment that will help maximise the value of the recovered materials.

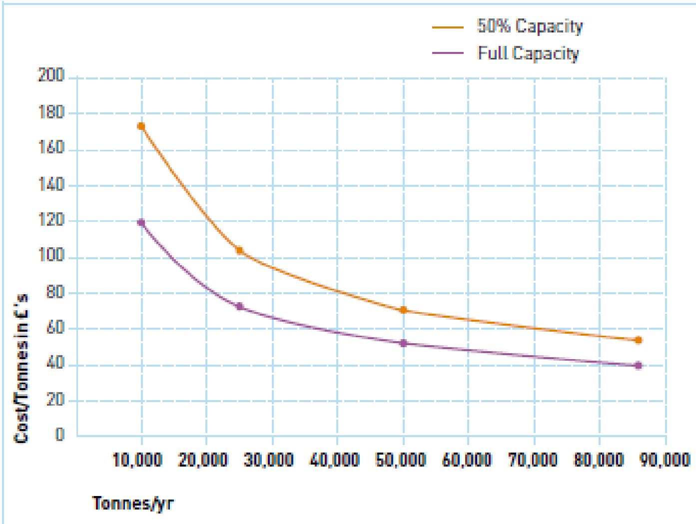

Figure 6. Specific processing costs in a fully co-mingled MRF

Source: WRAP, 2007

The cost curve in Figure 6 also shows the cost implications of operating a MRF at 50 % capacity (i.e. on a single-shift basis) compared to full capacity (i.e. a two-shift basis). The lowest cost curve for any particular MRF is that produced when the MRF is operating at full design capacity. Any reduction in throughput tonnage below that level increases the unit cost of processing.

Driving forces for implementation

The European Packaging Directive (1994/62/EC; 2004/12/EC amended) has been the most important driving force for the implementation of this best practice, as it introduced binding targets to collect, recover and recycle all materials used in packaging, including paper and cardboard, plastic, composites, aluminium and steel. Since then, most Member States have made major investments in packaging recycling systems. This has led to extended producer responsibility (EPR) regulations that ensure that manufacturers are responsible and have to bear the costs for the adequate treatment and recycling of packaging waste.

More recently, the implementation of the best practice has been reinforced by the recycling target set by the EU's Waste Framework Directive (2008/98/EC), requiring that "by 2020, the preparing for reuse and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight". The new Circular Economy Package, which includes revised legislative proposals on waste, further reinforces this target introducing a common EU target for recycling 65 % of municipal waste and 75 % of packaging waste by 2030. Also, the targets for limiting waste landfilling and related increasing of landfilling costs are relevant drivers.

Other important drivers for the implementation of this best practice, which in any case need to be substantially reinforced in EU countries, are the pull mechanisms for the creation of fully functional secondary raw material markets, such as economic instruments (i.e. tax reduction for companies producing recyclates, or lower taxes on products with recycled contents) or Green Public Procurement Policies (Plastics Recycling Europe, 2016).

Reference organisations

Based on available literature, in the UK (WRAP, 2009) there were 93 MRFs in operation in 2009, including both single-stream and dual-stream installations. In France (ADEME, 2013) 253 plants operate, 7 % of which (17 plants) are equipped with the most advanced sorting technologies. In Germany, the number of MRFs in 2011 was 92, but almost 90 % of the lightweight packaging collected was processed in less than 50 plants and, of these, 7 large plants were advanced sorting plants equipped with automated sorting of mixed plastics by resin type (Cimpan et al., 2015). Advanced MRFs are also operative in many other EU countries.

Examples of advanced MRFs identified are briefly described below:

- SUEZ MRF in Rotterdam, Netherlands: a technologically advanced sorting plant for co-mingled lightweight packaging (including plastics, metals and beverage cartons), with a treatment capacity > 17 t/hour, achieving a sorting rate of 89 % (3 % metals, 4 % beverage cartons, 45 % rigid PE, rigid PP, rigid PS, PET, PET film, 37 % mixed plastics). A video produced by the company is available at: https://www.youtube.com/watch?v=Xjot6NpySac.
- Alba MRF in Walldürn and Berlin, Germany: technologically advanced sorting plants for co-mingled lightweight packaging with respective treatment capacities of 170 000 and 130 000 t/year. A video of the Berlin plant produced by the company is available at: https://www.youtube.com/watch?v=CDGAhVb4r1w.
- Veolia MRF in Portsmouth, UK: a technologically advanced sorting plant for co-mingled lightweight packaging, applying an innovative sorting technology called "magpie" which separates mixed plastic into different waste streams. A video produced by the company is available at https://www.youtube.com/watch?v=iKuiyY6x0cc.
- Invader MRF in Willebroek, Belgium: a technologically advanced sorting plant for co-mingled lightweight packaging (including plastics, metals and beverage cartons), with a treatment capacity > 10 t/hour, achieving a sorting rate of 86 % (27 % metals, 12 % beverage cartons, 47 % clear PET, blue PET, green PET, rigid PE, rigid PP). A video produced by the company is available at: https://www.youtube.com/watch?v=AfP32IyqBak.
- Hera Ambiente MRF in Granarolo, Italy: a technologically advanced sorting plant for co-mingled lightweight packaging, equipped with two different treatment lines (one for paper and cardboard and one for plastics and metals), with an overall treatment capacity of 100 000 t/year. More information is available on the company website: http://ha.gruppohera.it/plants/main_plants/page105-082.html.

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