# PLASTICS RECOVERY FROM MUNICIPAL WASTE: MAINSTREAMS AND BY-PRODUCTS IN A CASE STUDY IN NORTHERN ITALY.

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SUMMARY: In the case study dealt with here, the factory treatments of dry Municipal Solid Waste are aimed primarily at materials recovery; restraining energy recovery to the hardly recyclable by-products. The main input consists of the so-called *multipak* from MSW source-sorted collection; plus packaging waste, paper and cardboard and other similar waste from curb-side collection. The principal fractions produced by the selection plant, own and operated by the Public Company in charge of MSW management, in the Year 2012 were 27 064 tonnes of plastics, 5 066 of paper, 3 014 of tin coated steel and 4 886 tonnes of extraneous fraction to dispose of. A minor – though valuable – product was aluminium. The immediate energy consumption indices were calculated for *multipak* processed in the factory; the homogeneous overall index is 238 MJ / t.

## 1. INTRODUCTION

The physical composition of Municipal Solid Waste (MSW) includes everywhere a significant fraction of plastics and rubber. In the case study dealt with in this paper, waste plastic treatments are aimed primarily at materials recovery; restraining energy recovery to the by-products hardly recyclable or non-recyclable at all.

In an area of about 1 300 square kilometres in Northern Italy, – mainly making the District of Monza and Brianza, the District of Lecco and some municipalities in the District of Milan – more than 1 million people generate every year 40 – 45 000 tons of waste dry fraction. A Public Company established in that area – namely, SERUSO SpA – owns and operates a treatment plant, whose main input consists of the so-called *multipak* from MSW source-sorted collection; plus packaging waste, paper and cardboard and other similar waste from curbside collection.

In this work the data required to draw the materials flows and balances were taken from the ordinary records kept at SERUSO SpA.

The main components of the plastic fraction contained in input material are PET (about 23 %) and PE (12 %). The outputs of the selection process consist in secondary raw materials (SRM), and extraneous fraction (EF). The former is sold to recycling industries, while the latter is sent to energy recovery by incineration.

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## 2. MATERIAL AND METHODS

### 2.1 Waste components and collection system

The MSW management system put into action in the catchment area studied starts with a household sorting system based on multi-bin curbside collection. The dry fraction is mainly constituted by packaging materials - identified as *multipack* - and after collection is transported and delivered to the "SERUSO" selection plant located in the area (Carcione et al., 2013).

In year 2012, *multipak* collected and sent to the selection plant was almost 43 000 tons and the principal fractions were 27 064 tons of plastics; 5 066 paper; 3 014 tin - coated steel; and 4 886 tons of extraneous fraction to dispose of. A minor – though valuable – product was aluminum, while Tetrapak was almost 1 800 tons. See Table 1 for the 2010 – 12 time span.

Table 1. Amounts of input "multipak" and its component fractions in tonnes, for the years 2010, 2011 and 2012.

| *Year* | *"Multipak" total input* | *Al* | *Tin coated steel* | *Tetrapak* | *Paper and cardboard* | *Plastics* | *Extraneous Fraction* |
|---|---|---|---|---|---|---|---|
| 2010 | 45 661 | 662.08 | 3 680.28 | 968.01 | 6 931.34 | 26 382.93 | 7 036.36 |
| 2011 | 43 920 | 707.11 | 3 737.59 | 2 174.04 | 6 491.38 | 24 494.18 | 6 315.70 |
| 2012 | 42 749 | 931.93 | 3 013.80 | 1 786.91 | 5 065.76 | 27 064.39 | 4 886.21 |

*Multipak* input stream is subjected to a chain of treatment stages to yield homogeneous fractions (see Figure 1).

Input material first passes through a procedure of acceptance, then is weighted and stored. Hauling in the plant area is made with machines such as forklifts, mobile material handlers and bulldozers. After the separation of homogeneous fractions there is a quality control stage. It consists in an automatic control carried out by an optical system, followed by a visual control in which specialized operators manually separate extraneous materials from homogeneous streams.

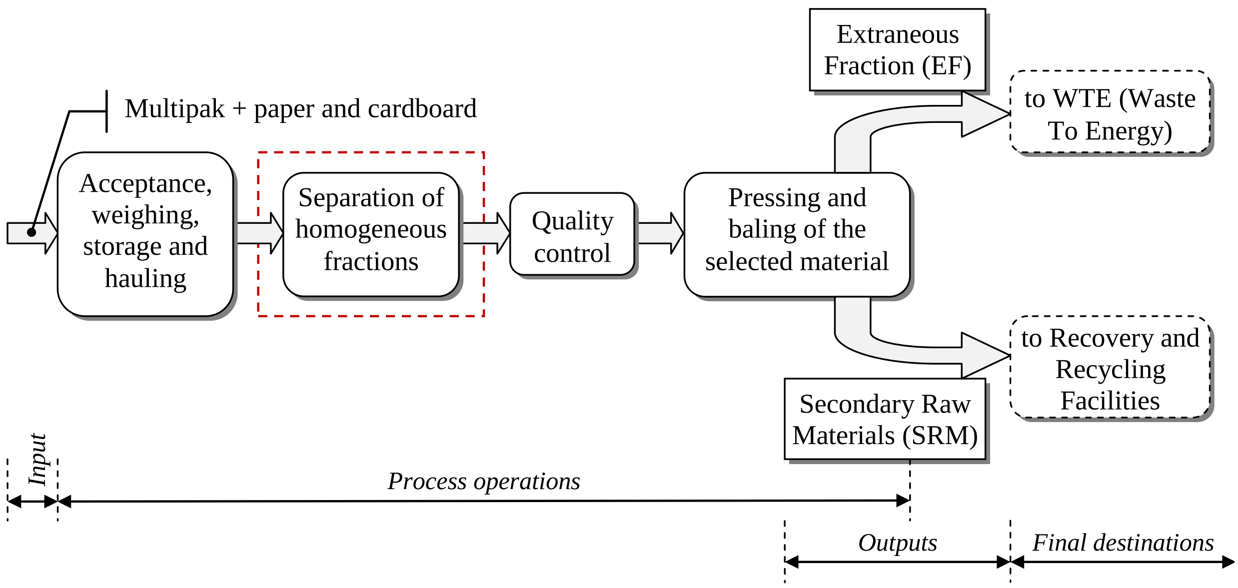


Figure 1. Main phases of the *multipak* treatment process with outputs and final destinations.

In the last stage pressing and baling of the selected material is carried out in a baling press machine. The output streams are 2, i.e. 1 mixed extraneous fraction and 8 or more distinct materials.

## 2.2 Selection process

### *2.2.1 Overview*

The separation of homogeneous fractions consists of several process operation carried out in dedicated machines (Carcione, 2013). The sequence of separation machines is depicted in Figure 2.

The principal machines operating in this stage are:

Bag opener machine
Rotating sieves
Ballistic separator
Magnetic separator
Optical separator

The bag opener machine tears the bags and discharges their content onto belt conveyors below, that carry the materials to the rotating sieves. The main stream coming out from these is a mean one containing plastics, paper, tetrapak, Al, and steel. The other two streams are: the coarse, made of plastic films and cardboard, conveyed to manual quality control; and the under-sieve – that is the fine fraction – intended for energy recovery in an incineration plant.

The mean fraction enters into a ballistic separator in which metallic components are separated from plastics, paper and tetrapak generating two output streams (Figure 2). The magnetic separator output is Al and steel. The optical separation system consists of specific optical separators for plastics, paper and tetrapak. It generates different types of plastics: light PET, blue PET, colored PET, PE, PE films in two different thickness and a mixture of PP, PS, PVC and other polyolefins.

Material discarded in each operation is redirected to the appropriate stream or in the fine fraction.

### *2.2.2 Energy consumptions*

The SERUSO selection and treatment plant uses electric energy and Diesel fuel to supply its operations.

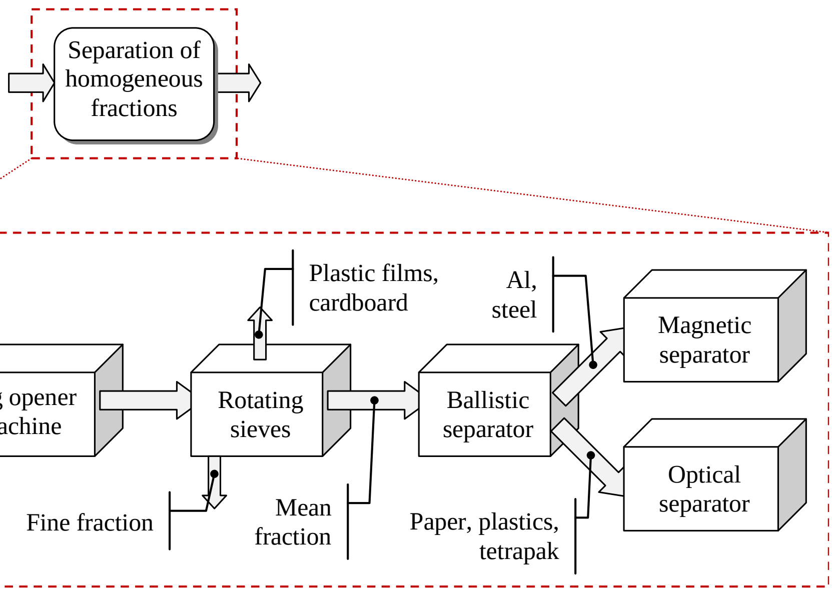


Figure 2. Detail of machines making up the operations in the stage of separation.

The primary energy consumption is electrical energy, which is used in most process stages. In year 2010 the company "La ESCo del Sole srl" carried out an energetic audit in the plant (Porcari and Gaburro, 2010). As a result of the audit electric energy (EE) is allocated by 83.5 % to production, 9.9 % to lighting and general services, and 6.6 % to indoor climate control.

Figure 3 shows the values of EE unit use for year 2010. The three items in Figure 3 are the result of merging the single voices considered in the audit.

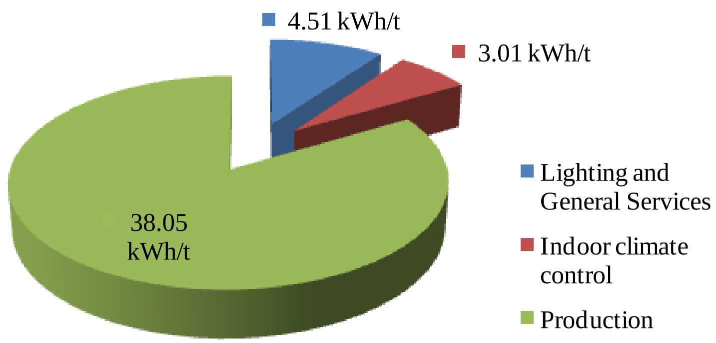


Figure 3. Unit electrical energy use in the whole factory (kWh/$t_{input}$ ). Values based on data of the year 2010.

Diesel fuel is used by vehicles and machineries that move input waste and its fractions around and through the plant. The amount of this fuel consumed in year 2012 was about 63 000 litres. In Table 2 electric energy and Diesel fuel consumptions are listed for the period 2010 – 2012.

Table 2. Electric energy and Diesel fuel uses at SERUSO for the years 2010 - 2012.

| *Year* | *Electrical Energy* | | *Diesel fuel, l* | *Diesel fuel, GJ* | *Total, GJ* |
|---|---|---|---|---|---|
| | *MWh* | *GJ* | | | |
| 2010 | 2 081 | 7 492 | 63 200 | 2 378 | 9 870 |
| 2011 | 1 989 | 7 160 | 69 500 | 2 615 | 9 775 |
| 2012 | 2 173 | 7 823 | 63 000 | 2 371 | 10 194 |

Table 3. Electric energy and Diesel fuel uses per ton of Multipak input.

| *Year* | *Multipak* | *El. En., MWh* | *Diesel fuel,l* | *Unit El. En., kWh/t* | *Unit Diesel fuel, l/t* | *Tot. Unit Energy, kWh/t* |
|---|---|---|---|---|---|---|
| 2010 | 45 661 | 2 081 | 63 200 | 45.56 | 1.38 | 59.33 |
| 2011 | 43 920 | 1 989 | 69 500 | 45.29 | 1.58 | 61.03 |
| 2012 | 42 749 | 2 173 | 63 000 | 50.84 | 1.47 | 65.50 |

The immediate energy consumption indices calculated for year 2012 are 50.84 kWh EE and 1.47 litres fuel per ton of raw *multipak* processed in the facility (see Table 3); the homogeneous overall index is 236 MJ / t (i.e. 65.50 kWh / t). This figure at a first glance appears insignificant compared with any of the two energy contents of the recovered materials, i.e. feedstock and embedded, which are in the order of ten thousands. This topic though will not be developed here.

### *2.2.3 Energy recovery from Extraneous Fraction (EF)*

The lowest measured LHV of the extraneous fraction (EF) is 9 720 kJ/kg. As EF amounts to about 12% of the entering *multipak*; if one credits to the WTE plant a mere 22 % efficiency (E) from HV to EE; it is easily calculated that incineration of EF discarded by SERUSO yields 71.28 kWh.

This is equivalent to 140 % of the factory's EE needs alone, or 110 % of its total energy needs. In fact, using the EF as the basis for calculating and indexing, the (energy / mass) ratio for the WTE plant is

$$\frac{\text{el. en. from EF}}{m_{\text{EF in}}} = \frac{LHV_{EF} \times E}{m_{\text{EF in}}} = 9\,720\left(\frac{MJ}{t}\right) \times \frac{1}{3.6}\left(\frac{kWh}{MJ}\right) \times 0.22 = 594\left(\frac{kWh_e}{t_{EF}}\right);$$

the ratio for the selection processes at SERUSO is

$$\frac{\text{el. en. used}}{m_{EF}} = 50.84\left(\frac{kWh_e}{t_{multipak}}\right) \times \frac{1}{0.12}\left(\frac{t_{multipak}}{t_{EF}}\right) = 424\left(\frac{kWh_e}{t_{EF}}\right);$$

from these we get a conservative value

(EE from WTE / EE used for selection processes) = (594 / 424) = 1.40.

In the following calculations, a higher and more probable LHV for cellulose and plastics will be used, namely 15 000 MJ/t. See Figure 4 for comparisons about E.E. produced / used in the time span 2010 – 2012.

## 2.3 Products destination and the recycling industry

### *2.3.1 A typical machinery setup and its electrical consumption*

Recycling factories, using mechanical, physical and chemical processes, actually transform sorted plastics - coming from facilities like SERUSO one - into purer fractions suitable as SRM, free of labels, cap rings., and like. For instance, PE fractions are reduced in grains that can be fused or extruded to manufacture new objects. Other fractions, like PET, are reduced in flakes or grains that can be used as additives in the manufacturing of thermoplastic polymers.

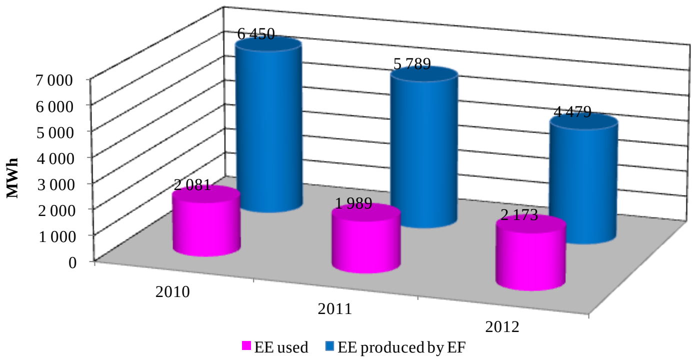


Figure 4. Electrical energy use (front) and electrical energy virtually produced by incineration of the extraneous fraction (back) for the years 2010 - 2012.

A typical machinery used to obtain flakes or grains with suitable dimensions is a blade mill. On the market there are mills with different power rating and different treatment capacity per hour; e.g., one of them can have a 110 kW drive with a capacity 1.2 t/h. The mean electrical consumption is about 90 kWh/t.

As just 0.63 t of selected plastics - out of 1.00 raw *multipak* - are delivered to recycling factories, we get immediately (90 × 0.63) = 56.7 kWh for recycle / t raw *multipak*.

We can easily verify that EE produced from an EF of mediocre HV (see 2.2.2) cannot satisfy also the energy needs for the mechanical steps of plastics recycling. In fact, the unbalance in the Authors' case study is [71.28 – (50.84 + 56.7)] = – 36.26 kWh/t raw *multipack*; in other words, 34 % of the energy needs for (selection + recycling) has to be satisfied with fresh electrical energy supply.

## 3. COMPARISON BETWEEN DRY AND WET SEPARATION PROCESS

The separation process at SERUSO plant is a dry process. This type of separation has some advantages on the wet one, as the use of washing water, centrifugal driers, and flotation tanks in the wet process entails the rise of energy consumption.

For a comparison between the two, data from different facilities using a wet process would be required. The Authors have at their disposal just some data from a plant studied few years ago and have used them, in the awareness that this comparison is not to mean as a general one.

The Authors' study on HDPE and PET treatment lines was carried out in year 2005 (Torregrossa et al., 2005). The two treatment lines were in service in a plant located in Sicily and were reciprocally integrated. Materials input consisted in waste from curbside collection, and scraps from industrial activities. Materials were delivered to the plant in bales or in bulk; both HDPE and PET were to be freed of metallic materials; in addition, HDPE was to be freed of traces of PET and vice versa.

The HDPE line consisted of a dry shredding, flotation, centrifugal drying, milling as principal operations. For the PET line wet shredding, water separation (by centrifuge), flotation, centrifugal drying, separation of metals were the main stages.

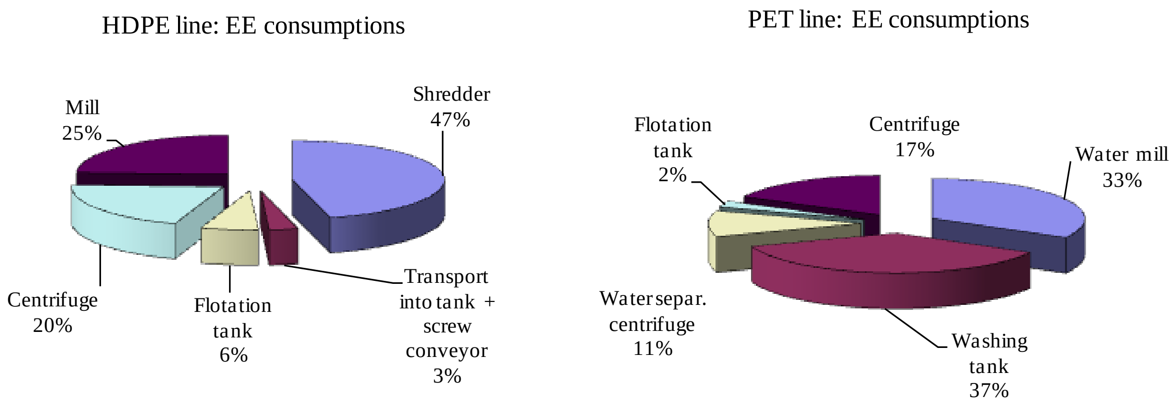


Figure 5. Electrical energy use distribution for the two "wet" separation lines of HDPE and PET.

The facility needed one cubic meter per day of makeup water, or 0.071 $m^3$/t. The total amount of EE was 184.02 kWh per ton of input materials for HDPE line and 216.20 for the PET line. The higher EE needs for PET separations were due to the operation of 2 centrifuges and to the considerable requirement of the washing stage.

The Figure 5 graphically illustrates the EE use distribution for the treatment lines of HDPE and PET. For a complete energy (and costs) balance, process water treatment before authorized discharge should be considered too.

HDPE and PET in pellets of about 12 mm were the output of the plant, ready to use as secondary raw materials.

## 4. RESULTS AND DISCUSSION

The records of 3 operation years at the SERUSO SpA selection plant - that makes the Authors' case study - demonstrate that about 35 % (w/w) of plastics input have been consistently transformed in homogeneous fractions, made up of PE and PET, as described in section 2.2. The remaining fraction of the plastics input (about 65 %) gives a mixture of other plastics (the so-called *plasmix*). All these exit flows are SRM for the recycling industries, as mentioned above.

Table 4. Electric and total energy use rates in the sorting plant and in a possible recycling industry.

| | Sorting plant | | | | Recycling industry | Sorting + Recycling | |
|---|---|---|---|---|---|---|---|
| *Year* | *Unit El. En., kWh/t* | *Tot. Unit Energy, kWh/t* | *Unit El. En., kWh/t$_{(PE+PET)}$* | *Tot. Unit Energy, kWh/t$_{(PE+PET)}$* | *Blade mills El. En. Consumption kWh/t$_{(PE+PET)}$* | *Tot. EE kWh/t$_{(PE+PET)}$* | *Tot. Energy kWh/t$_{(PE+PET)}$* |
| 2010 | 45.56 | 59.33 | 207 | 270 | 258 | **465** | **528** |
| 2011 | 45.29 | 61.03 | 206 | 277 | 258 | **464** | **535** |
| 2012 | 50.84 | 65.50 | 231 | 298 | 258 | **489** | **556** |

Two useful comparisons for the Authors' findings are offered by the treatise by Rigamonti and Grosso (2009) and from the Inventory of Carbon & Energy (ICE) by the University of Bath (2011). See Table 5.

Table 5. Comparisons between unit energy and embedded energy values from various sources.

| | *Values from Rigamonti and Grosso (2009)* | *Tot. Energy kWh/t$_{input}$ (this research)* | *Tot. Energy kWh/t$_{(PE+PET)}$ (this research)* | *Embedded Energy (ICE database) kWh/t* |
|---|---|---|---|---|
| Plastics selection | 26.6 kWh$_e$/t + 23.3 kWh Diesel/t | **65.50** | **298** | N. A. |
| PET recovery | 311 kWh$_e$/t + 750 kWh $CH_4$/t | N. A. | **556** (*) | 6 083 ÷ 42 583 |
| HDPE recovery | 379 kWh$_e$/t + 181 kWh $CH_4$/t | N. A. | **556** (*) | 5 167 ÷ 28 611 |

(*) selection included.

About the energy needs for sorting and for mechanically pre-treating the plastics, it is to remember that the factory starts from an input stream called *multipak*, and applies an entirely dry process. The unit rate calculated from the Company's recorded data is 50.84 kWh / t raw *multipak*.

As the grinding of plastics bales following requires 90 kWh / t (what makes 90 × 0.63 = 56.7 kWh / t raw *multipak*), we can say that the two stages of waste plastics recycling need nearly the same energy per unit materials input at the inlet of the chain. All the results of referring and indexing operations have been gathered in Table 4.

These requirements can be virtually satisfied – partially or entirely – if the extraneous fraction (EF) of *multipak*, consisting of paper, cardboard and mixed plastics, is sent to incineration with EE recovery. The virtual self - sustenance can go from just 2/3 – if the LHV of the EF is below 10 000 kJ/kg – to the fulfillment, if LHV exceeds 14 000. For instance, for LHV 15 000 MJ / t the energy from EF is about 110 kWh / t raw *multipak* or 500 kWh /t of PE + PET recovered.

## 5. CONCLUSIONS

This article summarises a study on the MSW management system in an area of Northern Italy, with particular emphasis on plastics recovery and on sustainability from the energy standpoint. The recorded data demonstrate that a- from a mixed dry waste, about 22 % (w/w) made of almost pure (PE + PET) can be consistently recovered; b- energy recovery from the incineration of the EF is widely sufficient for the total energy required at the selection plant, or, if including the blade mills in the recycling industries, for supplying the total electrical energy consumption.

The industrial cases studied by the Authors lead to state that a dry process of waste sorting aimed at plastics recycling is less energy – demanding that a wet one: indeed, the dry process used in the selection plant requires just about one third of the energy per ton of material input (kWh/t) of the wet one considered for the comparison. Although a wet process can reach a higher degree of selection, there is a limit in the materials separation that can't be overcome for economical reasons.

This integrate management system can be deemed sustainable also because the recycled plastics effectively reduce the needs of virgin plastics in the manufactory industries; with the associated environmental benefits, as the LCAs of packaging materials show (Rigamonti and Grosso, 2009; Hammond and Jones, 2011).

The possible savings / recoveries in Embedded Energy for the mainstream of the chain and for its most valuable by-products (metals) were not taken into account in the preceding calculations, and will be the subject of a next paper.

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