POLITECNICO DI TORINO

CORSO DI LAUREA MAGISTRALE

IN INGEGNERIA DELLA PRODUZIONE INDUSTRIALE E DELL'INNOVAZIONE TECNOLOGICA

TESI DI LAUREA MAGISTRALE

THE VALUE CHAIN OF ORGANIC WASTE IN A CIRCULAR ECONOMY PERSPECTIVE

ACEA PINEROLESE CASE STUDY: HOW TO MAKE A PROFIT OUT OF A COST

RELATORE

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A.A. 2018

A chi mi ha formato

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INTRODUCTION

The starting point of this study can be summarised by the following questions:

- Where is the borderline between product and waste?
- Would it be possible to transform waste in an alternative resource?
- What is the potential value of waste in relation with benefits and costs?

The study started with the previous questions whose answers were followed by one question each.

Availability and reliability of data have been the main obstacle of this study.

The first problem arose in outlining the context on a global level: in fact, there are only two exhaustive reports which monitor and track the problem, and the last update was done by the World Bank Group in 2012.

After outlining the context on a global level, the attention has narrow down to the situation in Europe, in Italy, in Piedmont, finally on the Metropolitan City of Turin and for a specific Consorzio.

The study continued analysing the main categories of waste and the related treatments to identify the fraction with the greatest potential in relation to the quantity produced and the disposal method.

It has naturally come to the contextualization of a Circular Economy perspective, as a characterising strategy of an economic system able to regenerate itself. (Ellen MacArthur Foundation, 2018)

Yet, in order to find an answer to the last question of the initial ones, it has been necessary to take into consideration an established, avant-garde example in the management and valorisation of waste: this is how Acea Pinerolese became the main subject of study.

Through the study of processes and input and output material, it has been possible to quantify the amount of organic waste transformed into new resources and the corresponding potential economic value.

Research findings are then presented, together with a final consideration and the conclusion.

1 CHAPTER ONE

WHAT IS WASTE: DEFINING A GLOBAL AND EUROPEAN SITUATION

1.0 INTRODUCTION

This first chapter aims to introduce and contextualise the topic of this study providing three backgrounds.

The first section tries to provide a comprehensive definition of waste from a legal and practical point of view, it categorises waste focussing the attention on the category of our interest.

The last three sections contextualise the topic by presenting the situation at a global, European and Italian level, focusing on waste level, waste composition, and treatment practices.

1.1 WHAT IS WASTE

Waste is a common word of ordinary use which could easily be misinterpreted and mislead. The question may be: in which phase of the lifecycle of a product it actually becomes a waste? For consumers, the definition of waste would probably involve the stage the product is thrown in the bin, yet not always a product in a bin can be considered as trash. An etymological definition offered by the *Oxford Dictionary* is: "unwanted or unusable material, substances, or by-product". Within this last definition, the mean of waste has become wider and objective: but which are the conditions to make something unwanted or unusable?

To clarify the concept of waste, the Commission of the European Communities, officially renamed European Commission with the Treaty of Lisbon in 2008 (European Parliament, Council of the European Union, 2007), has included its own definition, which reads as follow:" *waste* means any substance or object which the holder discards or intends or is required to discard" (European Parliament & Council, 2008), which has been unchanged since 1975.

The following diagram provides a graphical representation of the European definition of waste.

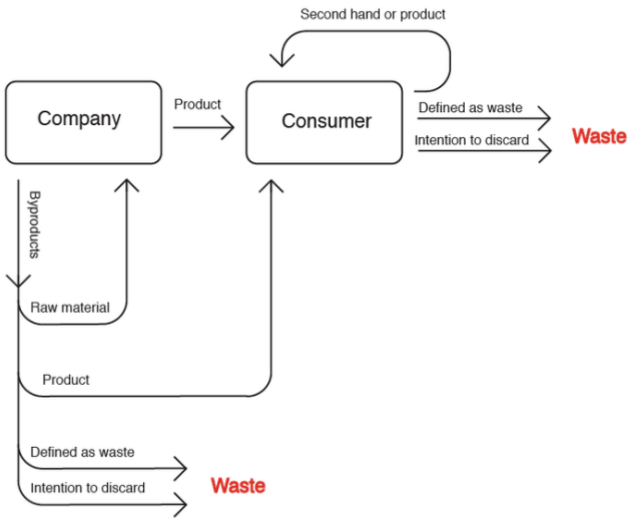

Figure 1-1: European legal definition of waste

Source: (European Commission, 2012)

Before assesing the global production of waste, it is important to clarify that there is not a worldwide common definition of waste, and it can change according to the country and the year. It can involve a list of defined physical substances, a legal definition, or combine these two aspects. In addition, the quality of data available depends on the policies, the government, and the level of development or income of the country. However, Figure 1 provides a wide definition which can be assumed to be accepted by every country.

After accepting the general definition of waste, a further division regards biodegradable and non-biodegradable waste: the first one includes any waste which can undergo aerobic or anaerobic decomposition, while the second one has to go through different waste flows.

This report aims to focus specifically on *municipal solid waste* (MSW), which includes waste generated by households, commerce, offices and public institutions and similar. (European Commission, EUROSTAT, 2017)

Figure 2 shows 5 macro waste categories, which are further divided in sub categories, and it allows to distinguish municipal solid waste from other categories.

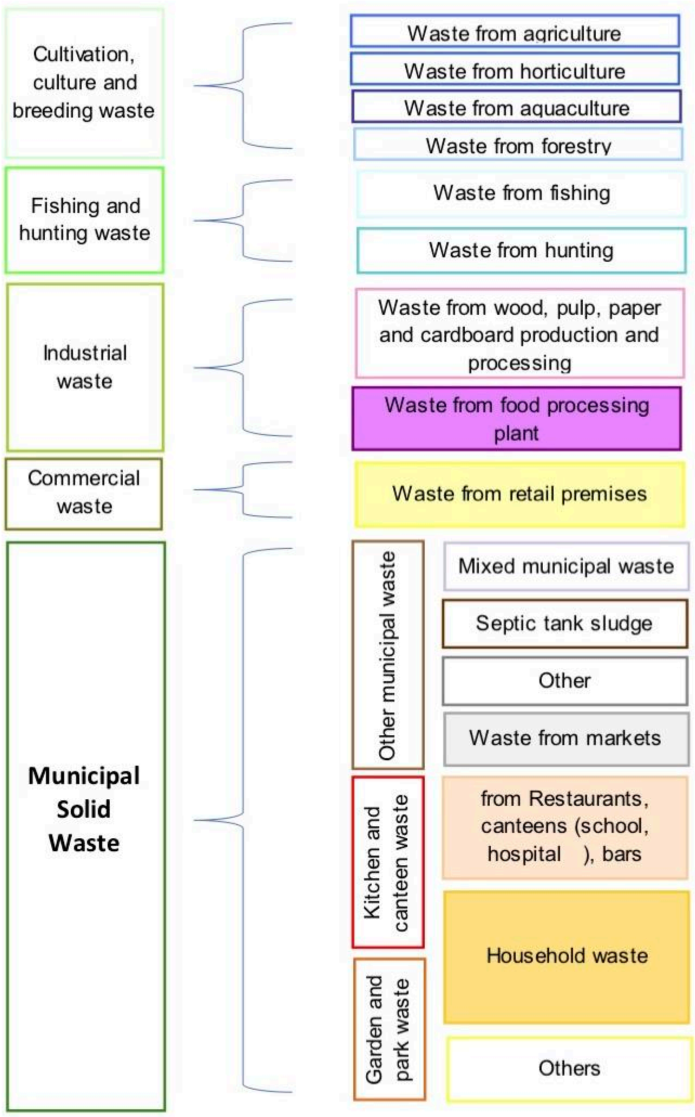

Figure 1-2: Main waste categories and its components

Source: (Manfredi & Pant, 2011)

All the considerations in the first sections come from the analysis of two main reports: *From Waste to Resource: An Abstract of World Waste Survey 2009* developed in collaboration with Veolia Environmental Services and CyclOpe and *What a Waste: A Global Review of Solid Waste Management* issued by the World Bank. These are the only two available reports trying to define and measure how waste has changed over time and its impact on present and future perspectives.

According to the United Nations Environment Programme and the two reports mentioned before, waste generation rate is raising due to rapid population growth and urbanization. It is important to mention the urbanization level to better understand that the composition and the level of waste produced per person increase as they live closer to an urban area, in general terms.

1.2 Global Situation

Below some figures regarding population and MSW generation:

- At the beginning of the 20th century, approximately 13% of the population lived in cities producing roughly 300 thousand tons of waste per day;
- In 2000 was estimated that 49% of people were living in cities, producing 0,64 kg of MSW per person per day, generating 680 thousand tons of solid waste per year;
- In 2012 was expected an increase of 0,1 billion urban residents reaching 1,2 kg of MSW person/day, a total of 1,3 billion tons per year of waste;
- An estimation for 2025 predicts 1,43 kg/capita/day and 2,2 billion tons per year;
- For 2050 the total population of 2000 expected to live in cities, drastically increasing the challenges related to municipal solid waste. (Hoornweg & Bhada-Tata, 2012)

World waste production and collection (estimated for 2006)		
	Quantities produced (tons)	Quantities collected
World total municipal waste	1,7 – 1,9 billion	65% - 73%
Manufacturing industry non-hazardous waste	1,2 – 1,67 billion	72% - 100%
Manufacturing industry hazardous waste for selected countries[1]	490 million	61%
Total per year	3,4 - 4 billion	69% - 81%

Table 1-1: World waste production and collection (estimated for 2006)
Source: CyclOpe and (Chalmin & Gaillochet, 2009)

In 2006, a figure of 10 million tons of waste per day, reaching 3 to 4 billion tons of waste per year worldwide, was accepted with 75% on average of it being collected and treated.

In Table 1-1, waste is composed of municipal waste, hazardous and non-hazardous for 2006, while in the rest of this paper only municipal solid waste is being considered.

In the following figure an attempt to catalogue waste production by region is shown, focussing on the percentage of production out of the total, and the quantity which is collected and recycled. Lack of quality

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[1] China, USA, EU28, Brazil, India, Indonesia, Japan, Turkey, Mexico, Bangladesh, Pakistan, South Korea, Thailand, Egypt, Philippines, Australia, Canada, Vietnam, Argentina, Morocco, Taiwan, Colombia, South Africa, Hong Kong, Venezuela, Chile, Singapore, New Zealand, Tunisia.

and availability data is the main limit, thus assumptions especially for the sub-Saharan African region and Eastern and Central Asia have been made.

Where possible, data were taken from the World Bank Group, governments official publications, international agencies reports, and articles in peer-reviews journals.

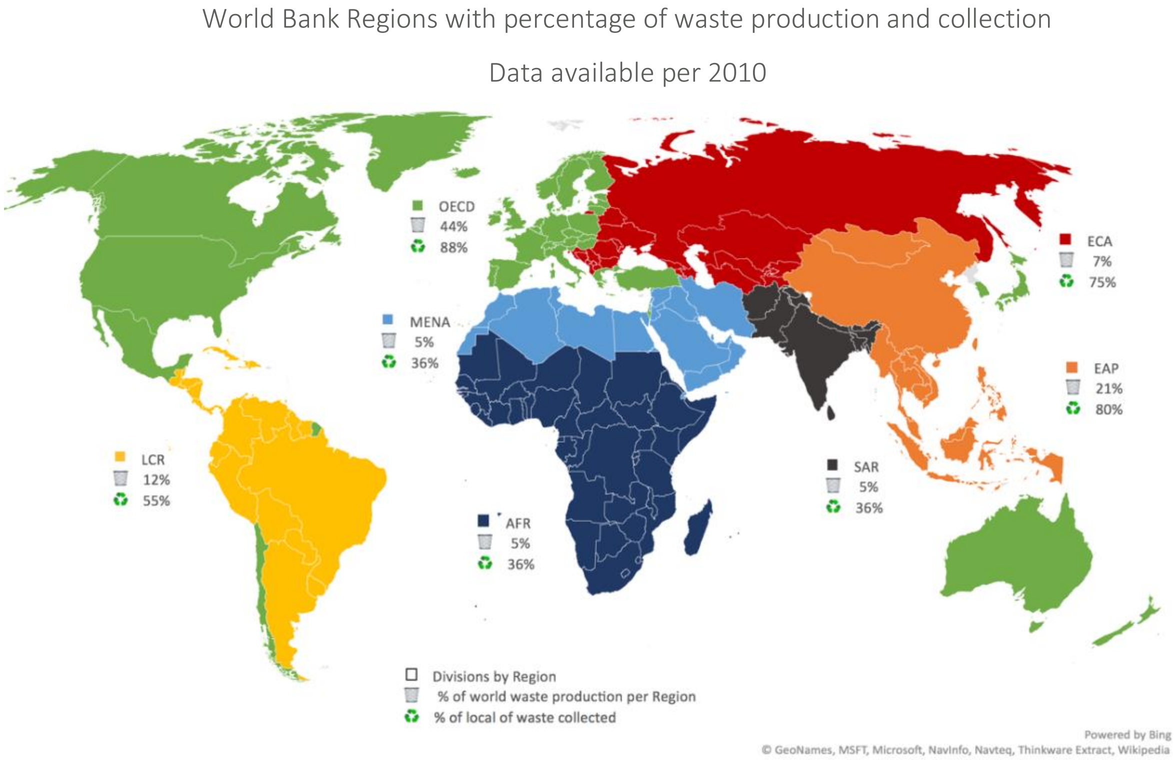


Figure 1-3: World Bank Regions with percentage of waste production and collection[2]

Source: (Hoornweg & Bhada-Tata, 2012)

As it is possible to assume, countries with a high-income economy are the ones with the higher rate of waste production.

Some highlights: 70% of the EAP waste comes from China, especially from urban areas, while the vast majority of waste is produced in the OECD countries with the USA and the EU28 on top, yet the waste issue is a top priority in these countries aiming to reduce the amount generated by optimising recycling processes and changing the perceptive of waste. In fact, waste can be further categorised as “waste” or “non-waste intended as: recovery, reuse, recycle”, focussing on the negative or positive market value. (Chalmin & Gaillochet, 2009)

[2] Region code details: AFR Africa Region; EAP East Asia and Pacific Region, ECA Europe and Central Asia Region; LCR Latin America and the Caribbean Region; MENA Middle East and North Africa Region; OECD Organisation for Economic Co-operation and Development; SAR South Asia Region.
Data and regions are estimated/defined from the World Bank and may not correspond to reality.

At a world level, landfill is still the most common and simpler method to disposal MSW, even if thermal treatments are vastly increasing in countries with higher income level which are focussing more on disposal methods rather than on collection; while in lower income countries open dumps are widely practiced because resources may not be available or there is low willingness to invest in technologies by the government.

In the following table, it is possible to find details per region as of 2010 and a projection for 2025, based on expected population growth rate, gross domestic product, and the estimation per capita waste generation. Analogue considerations were made in *What a Waste report* of 1999 mainly focused on Asia because of its exponential growth and projections for 2025 are still accurate, highlighting that non-sufficient improvements have been implemented and the trend has not changed. With the last figure, it is possible to compare regions, keeping in mind that waste of high-income countries contains more packaging and sophisticated products rather than organic/fermentable ones, while, on the other hand, lower income countries waste can contain up to 80% of the second type of waste. (Chalmin & Gaillochet, 2009)

Region Code	Urban Waste Generation					
	Available Data in 2010			Projections for 2025		
	Per Capita kg/capita/day	Total tons/day	% out of world total	Per Capita kg/capita/day	Total tons/day	% out of world total
AFR	0,65	169.119	5%	0,85	441.840	7%
EAP	0,95	738.958	21%	1,5	1.865.379	31%
ECA	1,1	254.389	7%	1,5	354.810	6%
LCR	1,1	437.545	12%	1,6	728.392	12%
MENA	1,1	173.545	6%	1,43	369.320	6%
OECD	2,2	1.566.286	44%	2,1	1.742.417	29%
SAR	0,45	192.410	5%	0,77	567.545	9%

Table 1-2: 2010 urban waste generation and an estimation for 2025

Source: (Hoornweg & Bhada-Tata, 2012)

A further analysis concerns the world composition of MSW collected by each region and data availability, and then aggregated assuming MSW was based on wet weight. Waste composition is influenced, as said before, by the income level of the country, by a mix of economic, cultural, and demographic factors, and its collection and disposal frequency.

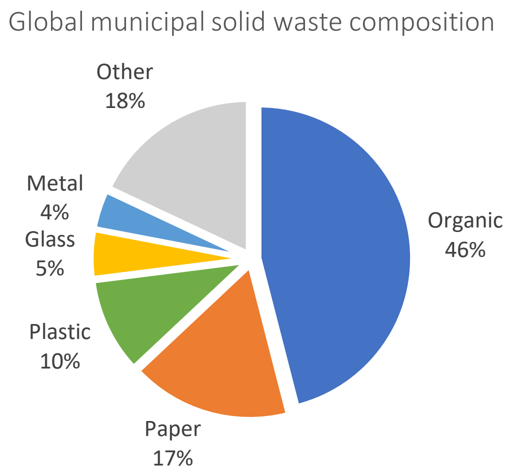


Figure 1-4: Global municipal solid waste composition, 2009

Source: (Hoornweg & Bhada-Tata, 2012)

Figure 1-4 is then extended in the following graphs for world regions, showing the percentage of municipal solid waste composition and represented in a clockwise order as follow: organic, paper, plastic, glass, metal, and other.

Together with Figure 1-3, it is possible to highlight that recycling percentage is directly proportional to organic fraction, while the percentage of plastic, glass and metal is approximately the same for each region.

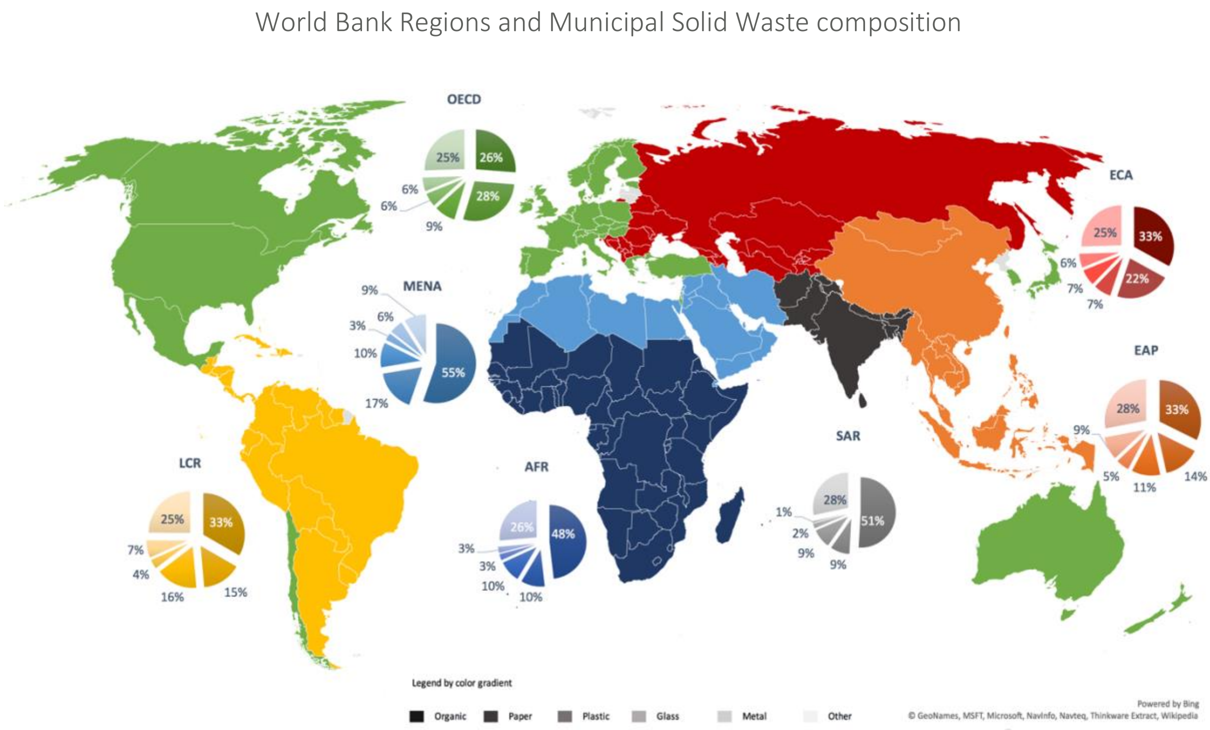


Figure 1-5: World Bank Regions and Municipal Solid Waste composition

Source: (Hoornweg & Bhada-Tata, 2012)

1.3 EUROPEAN SITUATION

Waste has been of interest for the EU commission in the context of the EU environment policy, with targets agreed between the 28-member states in programs such as the 7th EAP, Horizon 2020, and the EU Emissions Trading System.

Though, which activities produce waste, and which one reflects the country's attitude with regard to waste? The following graph shows the answer to the first part of the question.

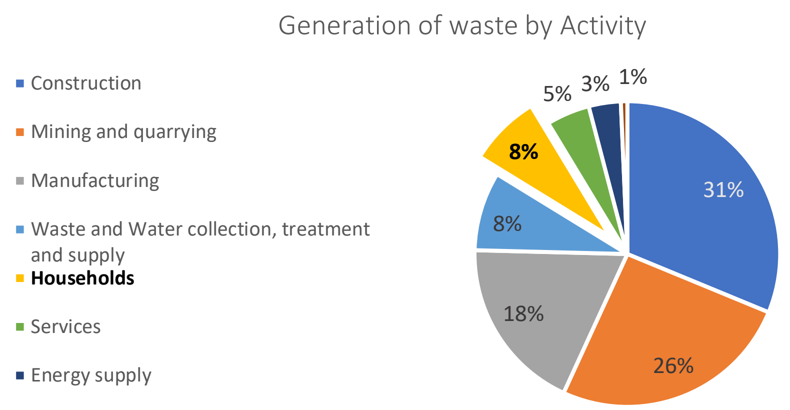


Figure 1-6: Generation of waste by Activity as of 2014

Source: Data from Eurostat

Counting from approximately 7 to 10% depending on the country, households waste stream reflects the overall quality of the waste management system, as it is considerated amongst one of the most complex to manage; therefore, it is worth to analyse it to generate an overview for the reader. (European Parliament, Council of the European Union, 2018)

As it is possible to notice from Table 1-3, in the last years the amount of waste is slowly increasing rather than decreasing, and this could be connected to a greater information sharing, openness, and data sharing collected by the EU and in each member states, which has promoted the adaption of more energy efficient and environment friendly product, instead of older ones.

Municipal waste generated in thousand tons								
GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017 (Estimated)
EU28	253.923	250.644	244.984	242.204	242.896	244.823	246.377	247.781
% variation	-	-1,3%	-2,3%	-1,1%	+0,3%	+0,8%	+0,6%	+0,6%

Table 1-3: Municipal waste generated in the European Union in thousand tons

Source: Data from Eurostat, 2018

On an overall analysis, the level of waste generated in the EU is steady. Yet, there are countries which can be defined as main producers: Germany is on top, producing more than a fifth of the entire production; France, UK, and Italy together reach almost 40%, as much as the other countries combined together. As the following graph shows, the top six countries for municipal waste generation reach 73% of the total generated, highlighting a big discrepancy between them and the other 22 countries of the EU.

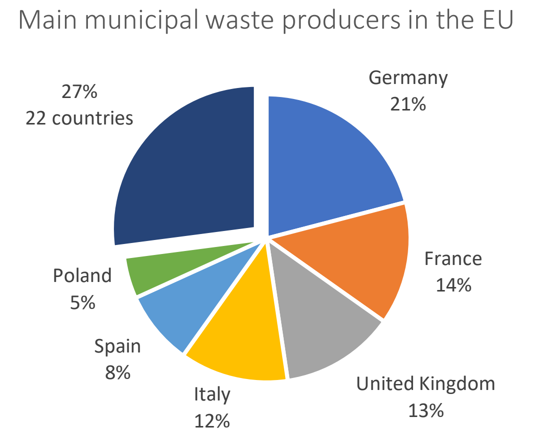


Figure 1-7: Main municipal waste producers in the EU for 2016

Source: Data from Eurostat, 2018

It can be of interest to analyse the average MSW composition for the EU: paper and organic waste account for more than 50%, while another 30% includes plastic, glass and metal. In the category *Other* is included waste generated from household activities and similar which do not fall in other categories.

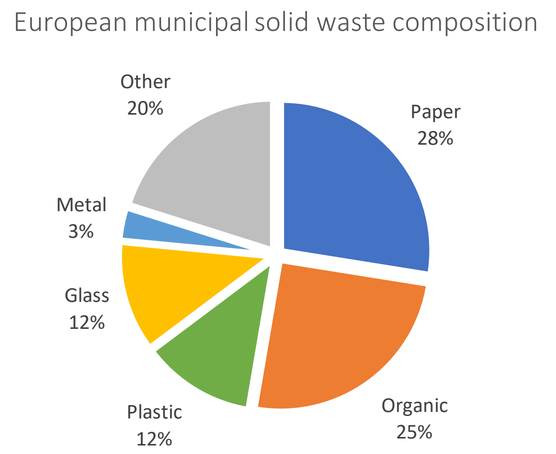


Figure 1-8: European municipal solid waste composition

Source: (Hoornweg & Bhada-Tata, 2012)

A further comparison can be seen in the waste generated per capita, which allows to better compare countries according to their population density, giving the same measure of unit. The EU average is of 473 kg per person, but again there is a strong discrepancy between countries: comparing Figure 1-7 with Figure 1-9, it is possible to notice that Germany is the only country present in both; while Denmark, hardly reaching 2% of total EU MSW production, is the only country generating over 700 kg per person of waste per person, 64% over the European average. On the other hand, Romania, Poland, and Czech Republic are the last on the list, with very low production, while the other countries mentioned before all fall in the EU average figure.

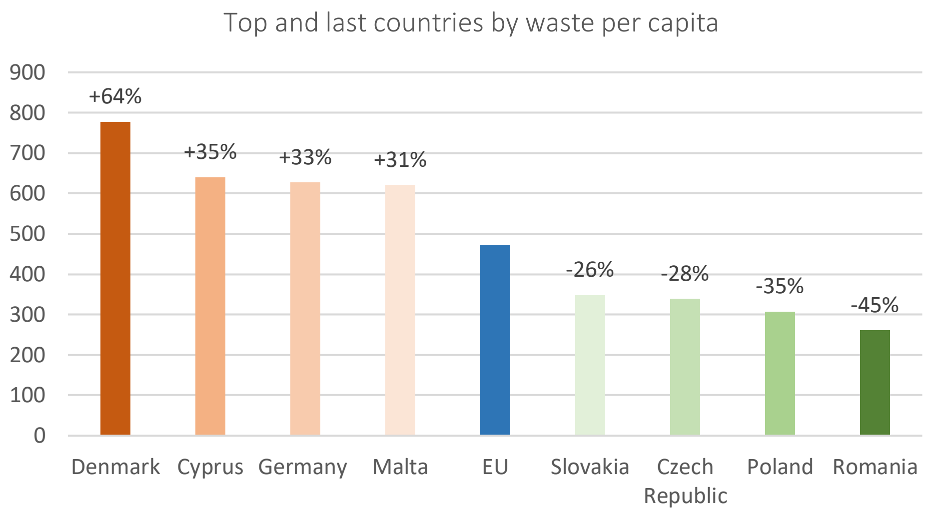


Figure 1-9: Top and last countries by waste per capita

Source: Data from Eurostat, 2018

Apart from waste generation, it is more relevant to understand how each country deals with recycling procedures and processes. The left side of following graph takes into account the total recycling collection rate of municipal waste: the EU average rate is at 39% having countries with higher GDP consider waste as a real problem to deal with, showing rate above 48%, while countries with lower GDP and islands in general have scored lower rates i.e. Cyprus, Malta, and Romania.

On the right side, recycling and landfill rate are compared together to highlight if there are situations with a negative correlation of the two rates, and then the total ratio is balanced with the amount of MSW produced per capita; the rank is from A (good level) to D (bad level).

From a general overview, both graphs show similar results with a few exceptions, from which it is possible to say that recycling and recycling/landfill rates have no special correlation with the amount generated per person.

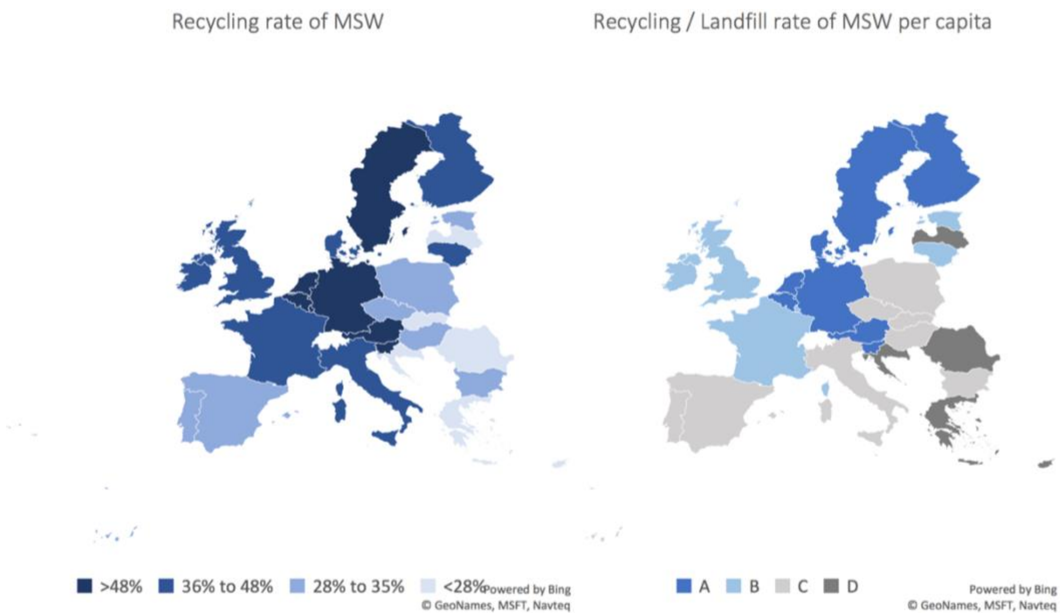


Figure 1-10: Comparison of Recycling Collection rate and Recycling/Landfill rate of MSW

Source: Data from Eurostat, 2018

What happen if import and export waste is taken in consideration? This is another relevant parameter to consider, as there are countries which exchange or sell waste at an international level when they are not able to dispose it by themselves.

The following graph shows the percentage of total import and export of municipal solid waste produced in each member of the EU, and it is sorted by the import percentage, having Luxemburg as the main and only importer above 5%, reaching 31%. These figures are relevant for further consideration in this chapter.

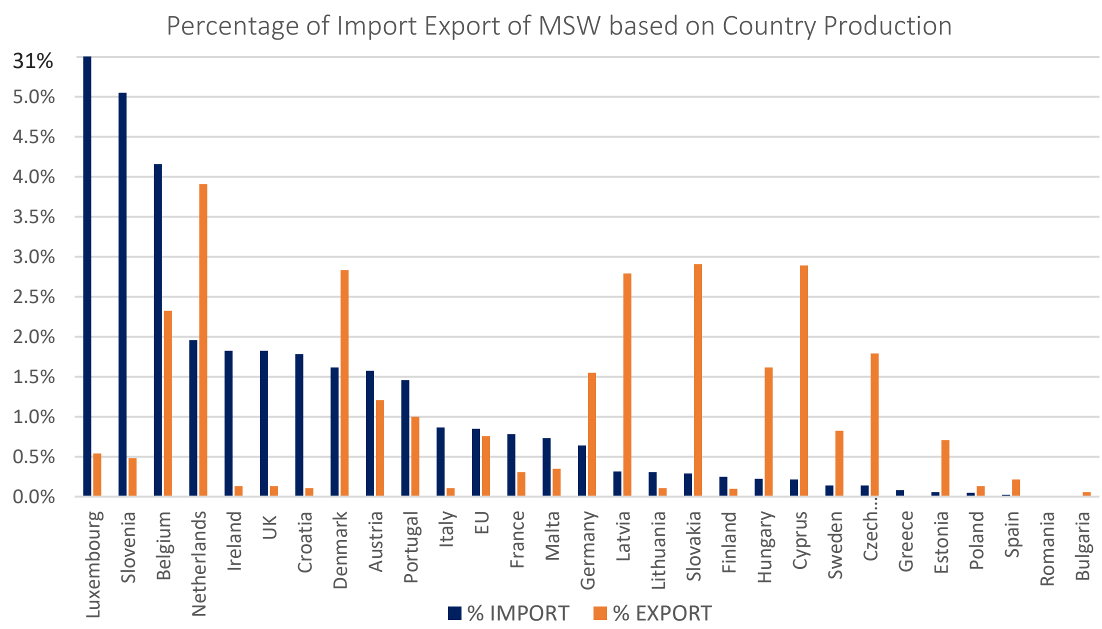


Figure 1-11: Percentage of Import Export of MSW based on Country Production

Source: Data from Eurostat, 2018

A tool for general comparison would include kg per capita, R rate, and the net import export of waste calculated with the following formula:

$$Formula = \ Net\ Kg\ per\ Capita * (1 - R\ rate)$$

Adding to the net kg per capita the net import export figure per capita:

$$Net\ Kg\ per\ Capita = Kg\ per\ Capita + (Import - Export)\ per\ Capita$$

And considering the recycling plus the energy recovery rate, defined as processes able to add value to waste resulting in a reduction of cost, and excluding incineration and landfill ones:

$$R\ rate = Recycling\ rate + Energy\ Recovery\ rate$$

The result provides a weighted value of waste per capita which is going to landfill or incineration, which have been ranked in intervals with a mark from A (best) to G (worst), depending on the distance from the European average value. In this rank, discriminating factors are how waste is treated among the total treated in the country.

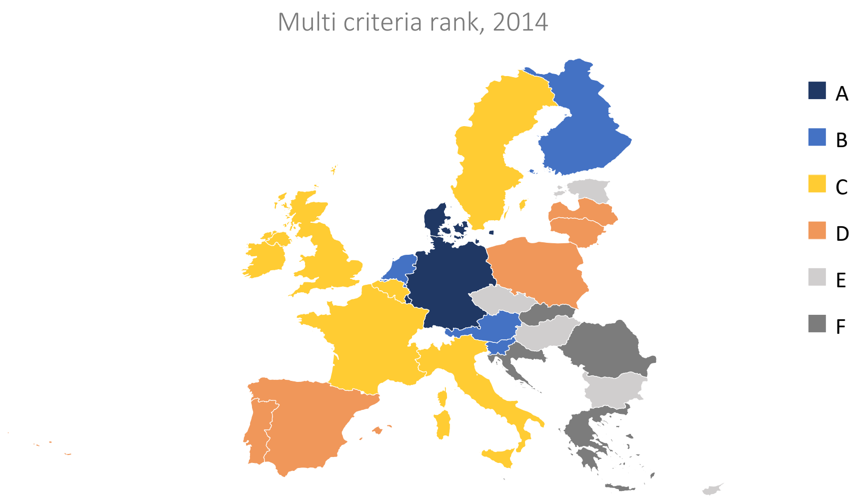


Figure 1-12: Multi criteria rank, 2014

Source: Data from Eurostat, 2018. Data for Luxemburg, Germany, Austria, and Czech Republic refers to 2012

As it is possible to notice with this ratio, top and bottom countries in Figure 1-10 have not changed; it is possible to see that Germany, Luxemburg and Denmark are the only three on top, while countries with a high landfill rate have the worst grade. Let's focus on the top three:

- Germany is on the top thanks to a very high waste to energy rate but average recycling rate at 14%, the rest is incinerated, while landfill rate is the lowest of Europe, at just 0,34%;
- Luxemburg produces more than 600 kg per capita per year and imports an extra 31% and export 0,5% and an average rate of recycling composting;

- Like Germany, Denmark has a very high waste to energy ratio and a record in kg per capita with a low import/export rate.

Looking at waste treatments, a different and interesting analysis can be conducted on how each country deals with the waste generated and imported/exported, whose percentage goes back into the production cycle, which is disposed in landfills, incinerated, or does not fall in one of the previous categories: then it is assumed that quantity is treated in a different country, as it is given by subtracting the total waste treatment from the total waste generated.

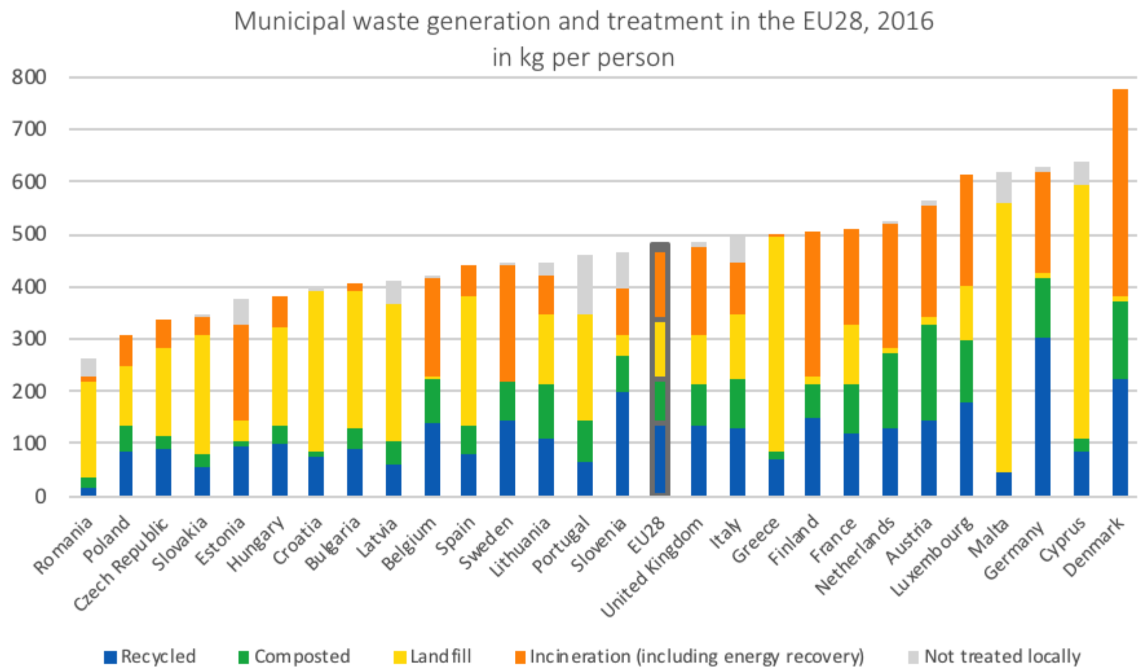


Figure 1-13: Municipal waste generation and treatment in the EU28 (excluding Ireland) for 2016 in kg per person
Source: Data from Eurostat, 2018

On an overall analysis, 29,3% of the waste was recycled and 16,6% composted, accounting for 46% of the total production; another 24,1% landfilled, 27,6% incinerated and another 2,5% was not treated locally. Since 1995, waste treatment practices have improved considerably, with an average increase of +4,4% of recycled and +2,3% of composted in a 5 year period from 1995 to 2015.

Looking at the scenario of the Union's economy only, for 2013, approximately 64% of the total 2.5 billion tons of waste generated were not recycled or reused, missing out increase: the potential of a significant amount of secondary raw materials, resource efficiency, and the creation of a more Circular Economy. (European Commission, Directorate-General for Environment, 2015)

However, the majority of improvements has to be attributed to countries which already had a stable and prosperous economy, while there is still a relevant variation in waste treatment across the members of the European union.

In the following figure it is possible to have a European overview of Figure 1-13 in pie charts.

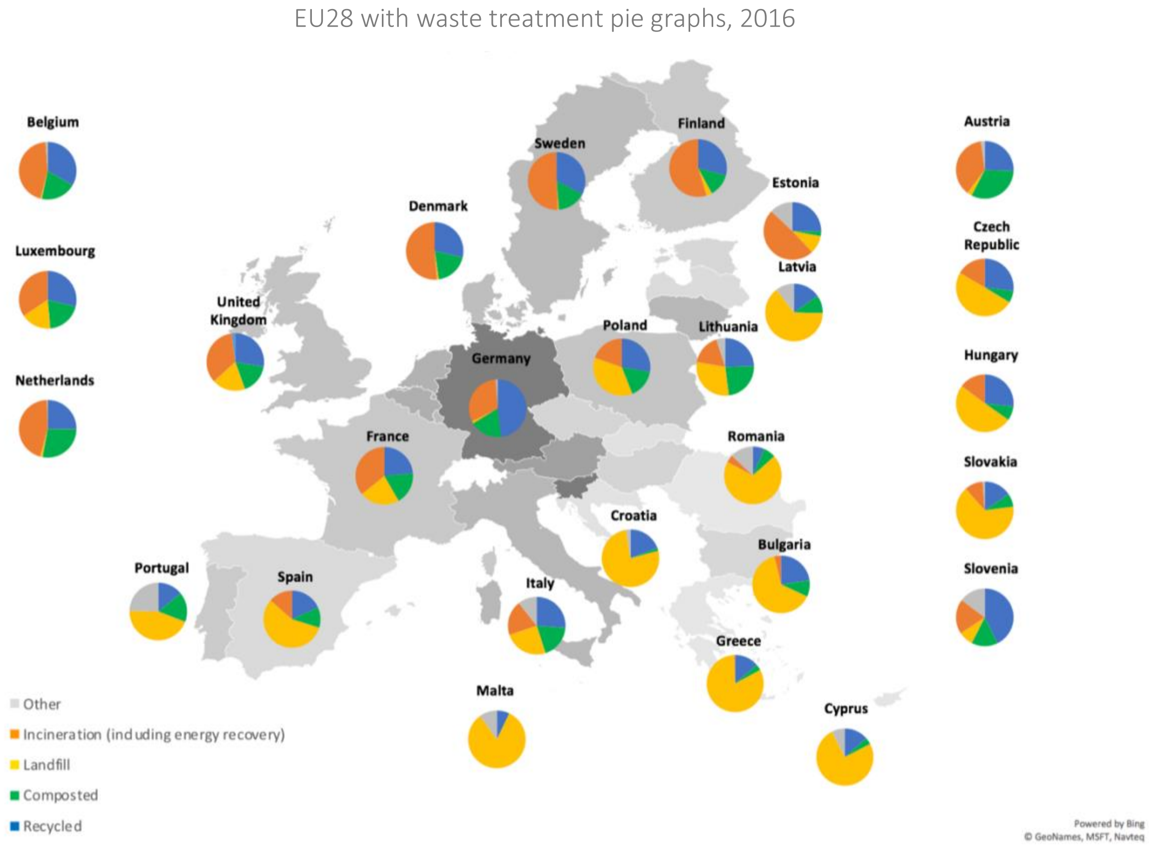


Figure 1-14: EU28 with waste treatment pie graphs, 2016

Source: Data from Eurostat, 2018

1.4 An Italian overview

As it is possible to see from the previous chapter, Italy is the 4th main producer of waste and it is above the average level of the EU28 in waste generation per person, occupying the 17th position.

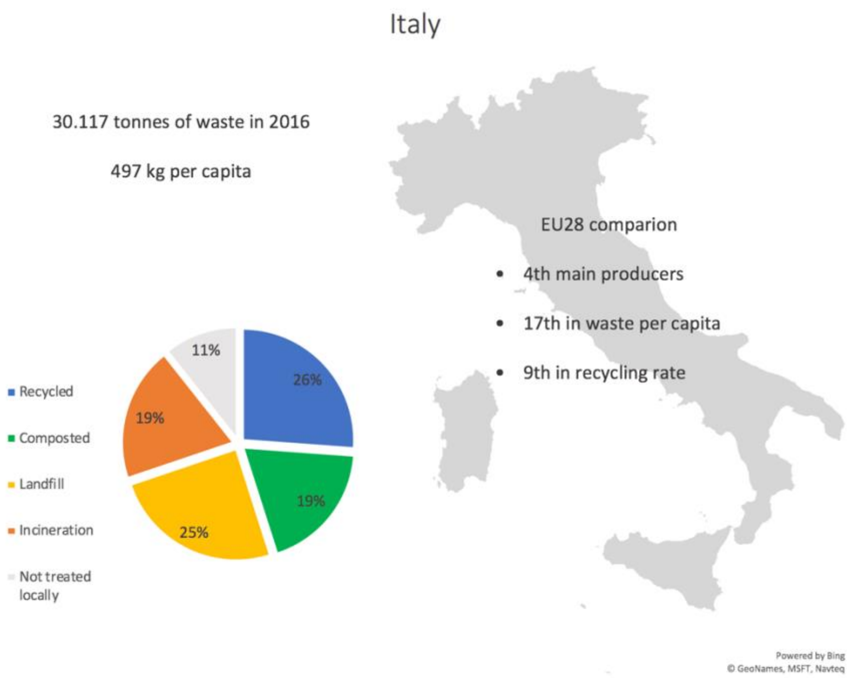


Figure 1-15: waste overview for Italy, 2016

With an amount accounting for the 12,2% of total EU production, Italy is slightly above the European Union average, allowing to easily compare the Italian situation with the European one.

In Table 5, it is possible to notice how Italy is doing versus the average waste treatment of the EU.

Data for 2016	Waste treated (sorted + unsorted)	Material recycled	Composting and digestion	Landfill	Incineration
Italy	89,3%	26,1%	19,0%	24,7%	6,6%
EU28 (estimation)	98,3%	29,2%	16,6%	24,0%	2,6%
Comparison	-9,0%	-3,1%	+2,4%	+0,7%	+4,0%

Table 1-4: a comparison of waste treatment between the EU and Italy for 2016

Source: Data from Eurostat, 2018

Focussing on an Italian perspective, it is possible to better understand the behaviour adopted by the country in its internal main divisions.

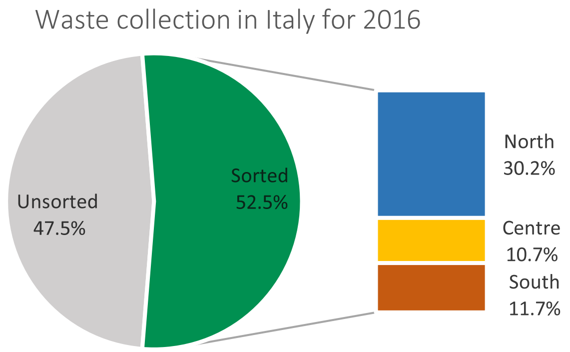
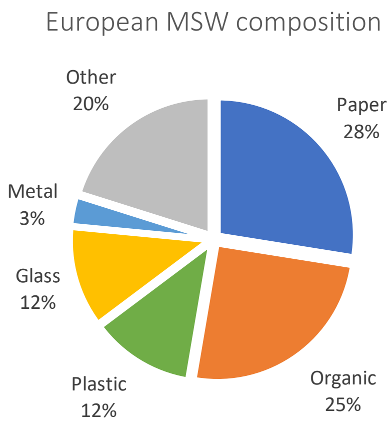
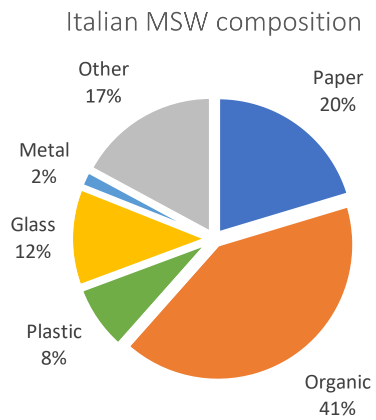


Figure 1-16: Waste collection in Italy for 2016

Source: Data from ISPRA, 2018

The Italian MSW composition just in parts reflects the EU composition, with a higher percentage of organic waste. It is possible to further analyse the Italian internal main divisions in the following table.





	Europe	Italy	North	Centre	South
Paper	27,5%	20,3%	19,1%	24,7%	19,6%
Organic	25,2%	41,2%	39,3%	41,8%	45,7%
Plastic	12,1%	7,8%	8,0%	6,1%	8,7%
Glass	11,7%	11,7%	12,0%	11,5%	11,2%
Metal	3,4%	1,9%	2,0%	1,7%	1,5%
Other	20,1%	17,1%	19,6%	14,2%	13,4%

Table 1-5: European vs Italian MSW composition

Source: data from ISPRA

In fact, as shown in the next table, it is interesting to notice that the Southern Italy produced less waste per person if compared with the other two divisions, yet the amount of sorted waste is around 38%, with the lowest point at 15,4% in Sicily, slightly higher than half of the second lowest region. On the other hand, Northern Italy was able to sort more than 64% of waste per person, with an overall less impact on the environment.

	Sorted waste in kg per person	Total waste in kg per person
Italy	**261,13**	**497,06**
North	327,72	510,16
Centre	266,36	548,05
South	169,21	449,96

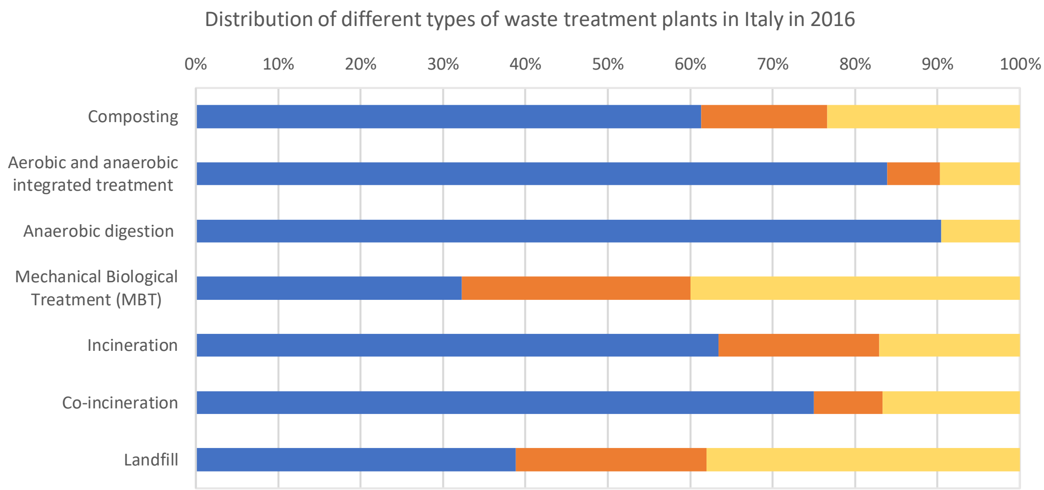
Table 1-6: Total and sorted waste in kg per person in 2016
Source: Data from ISPRA, 2018

The situation reflects the different policies adopted by each region and then by each municipality, coordinated and promoted by the Italian state, delegating the authority and the responsibility at a lower level, maintaining the following main competencies:

- Encouraging recycling and the recovery of material from waste in the whole state;
- Defining technical standard and guidelines related to waste management;
- Determining the criteria regarding the quality and quantity of waste for collecting and disposal purposes;
- Defining the guidelines for tenders and the admission requirements of companies. (D.lgs 3 aprile 2006, 2018)

Other competencies related to the optimal amount, location, and types of waste treatment plants, the adoption of a waste management plan, as well as the budget dedicated to this purpose are in charge of each region, which then delegate further responsibilities to the municipalities.

Because of this reason, it is possible to notice the gap of waste treatment distribution plants between the Northern, Central and Southern Italy. Furthermore, the following table does not highlight the difference in technological innovation, quality standards, and functional level of plants located in different macro area, which still marks a virtuous difference of the North in waste management and recovery.



	Landfill	Co-incineration	Incineration	Mechanical Biological Treatment (MBT)	Anaerobic digestion	Aerobic and anaerobic integrated treatment	Composting
North	52	9	26	42	19	26	168
Centre	31	1	8	36	0	2	42
South	51	2	7	52	2	3	64

Figure 1-17: Distribution of different types of waste treatment plants in Italy in 2016

Source: Data from ISPRA, 2018

2 CHAPTER TWO

AN OVERVIEW OF PIEDMONT, FOCUSING ON THE METROPOLITAN CITY OF TURIN AND ATO ACEA

2.0 INTRODUCTION

The second chapter aims to contextualise the topic defined in the previous chapter concerning the geographical area taken in consideration in the next chapters.

The first section contextualises the topic by comparing the Italian situation of waste with the region of Piedmont, with special attention on the Metropolitan City of Turin.

It follows a description of the waste management system adopted and a focus on ATO Acea, as it is going to be the cornerstone of this study.

2.1 PIEDMONT AND THE METROPOLITAN CITY OF TURIN

Accounting for 7% out of the national production, Piedmont has produced an average of 462,8 kg per person of municipal solid waste.

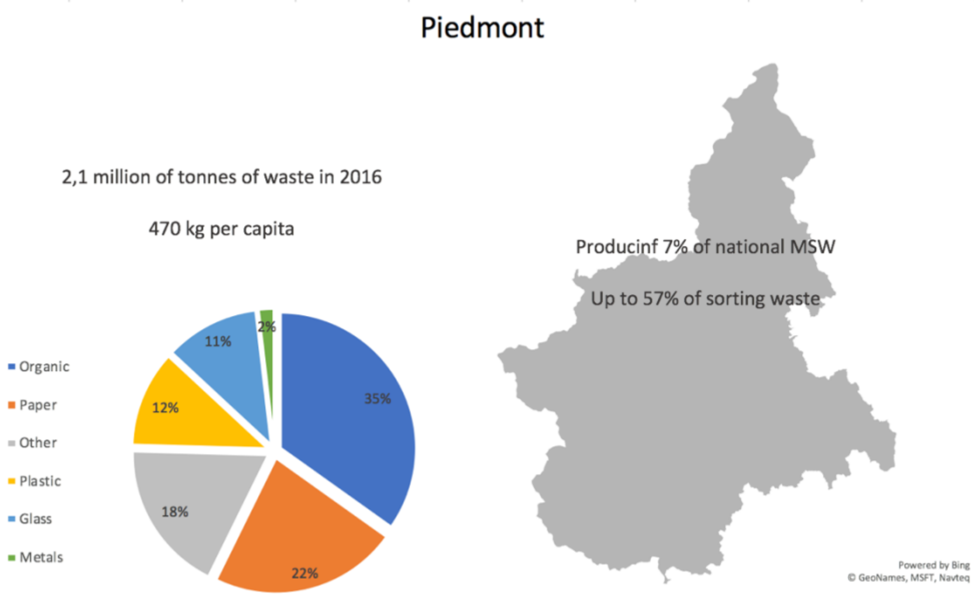


Figure 2-1: waste overview for Piedmont, 2016

Source: Data from ISPRA, 2018

In 2014 waste production reached a +2,35% in contrast with a previous reduction trend, and since then it keeps on increasing slightly, while the amount of waste sorted is steady at around 56%.

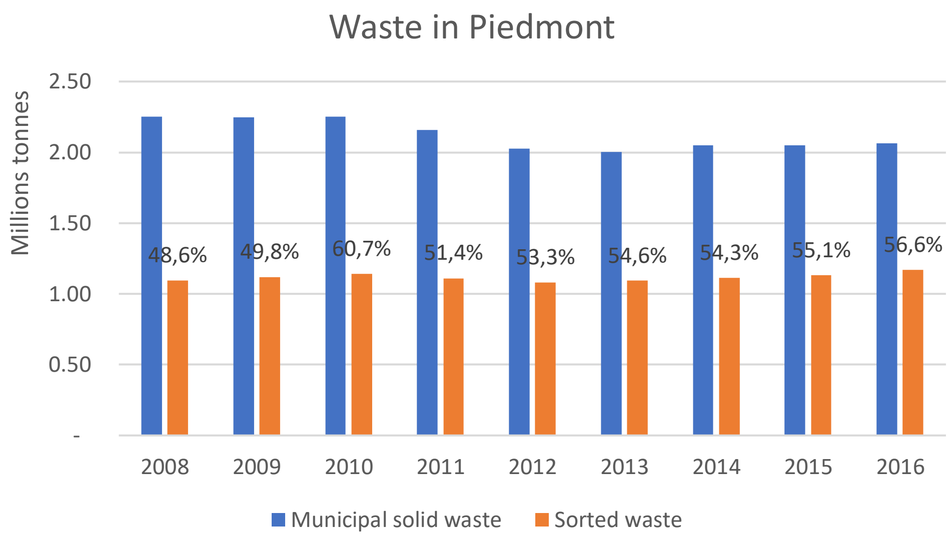


Figure 2-2: total waste in Piedmont

Source: Data from ISPRA, 2018

Organic waste has steadily increased since 2000, and now it amounts to 35%, followed by paper and plastic.

88% of unsorted waste, which corresponds to total MSW minus sorted waste, has been used to make new energy (48%) and for mechanical biological treatment (40%), while just 12% has been sent to landfill. As the quality of sorted waste is increasing, also the amount of waste sent to disposal plants has decreased of 47% in contrast with 2002 level: for example, 93% of waste which in 2002 would have been disposed in a landfill, now is sent in waste-to-energy plants. (Arpa Piemonte, 2017)

As of 2015, in Piedmont there were:

- 1 cogeneration plant;
- 1 incineration plant;
- 15 landfills for MSW;
- 10 mechanical biological treatment plants.

The Metropolitan City of Turin, which is going to be the focus of our analysis, shows a reduction in inhabitants equal to -0,2% which, together with an increase in waste production, has a waste production increase of +1,2% kg per person, now reaching 457 kg/person. However, looking at the following graph, it is possible to see that Turin followed the regional and national trend, yet it is below the average.

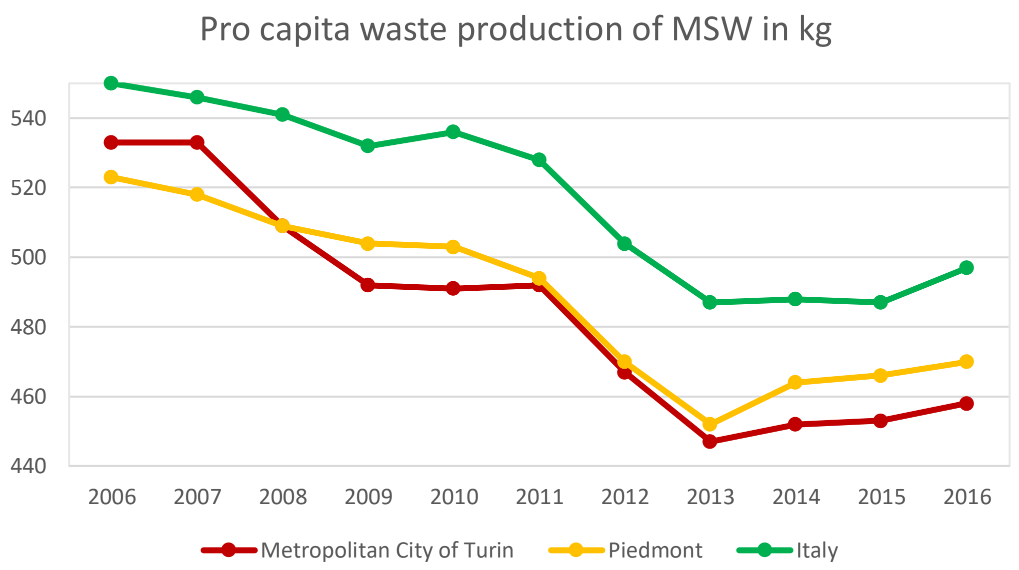


Figure 2-3: pro capita waste production of MSW in kg

Source: Data from Osservatorio Rifiuti, 2017

Piedmont and the Metropolitan City of Turin have adopted the Circular Economy approach promoting a more sustainable practice in the collection and treatment of waste, while reducing the total amount produced and aiming to achieve 190 kg per capita of unsorted MSW. (Regione Piemonte, 2018)

2.2 WASTE PRACTICES

In Piedmont, the urban waste management system is divided into optimal management areas, which consist of interconnected activities and structures aiming to reduce the environmental impact regarding the collection, transportation, recovery and disposal of urban solid waste.

These areas are technically called Ambiti Territoriali Ottimali (from here on referred as ATO): there are six ATO in total, which correspond to each province plus the Metropolitan City of Turin: each of them has the duty to supply and maintain plants for waste recovery and disposal. ATO are further divided into groups of uniform municipalities, called *bacini*, which have the duty to control and prevent the production of urban waste, to collect and transport it to recovery or treatment plants. (Regione Piemonte, 2018)

To ensure a homogeneous management of urban waste, three main criteria have to be satisfied: independency, proximity, and efficiency-effectiveness-affordability; to do so, the government and coordination functions are entrusted to the *Consorzi obbligatori di bacino*, consisting of a group of municipalities located in bacino.

Taking the Metropolitan City of Turin as an example, it has 7 bacini and 8 consorzi obbligatorio di bacino for a total of 316 municipalities and 2.2 million inhabitants, around 40% of the ATO population.

ATO-R (Associazione d'Ambito Torinese per il Governo dei Rifiuti) is the government body for the Metropolitan City of Turin responsible for the urban management system of the ATO considered. It regulates and determinates the target to achieve according to the efficiency, effectiveness, cost and transparency criteria set on the three following levels:

- It organizes plants system for the disposal and treatment of the bacino, which programs the relative waste flows to the plants and establishes the transfer rates;
- It entrusts the realization and management of the plants and of the relative service to the companies entrusted;
- It controls and checks the quality, effectiveness, and result.

The following table to identify the Bacini and the corresponding consorzio, followed by a map representation.

Bacini	Geographical area	Consorzio name	Acronym	Number of municipalities	Inhabitants	%
12	Pinerolese	Consorzio Acea Pinerolese	ACEA	47	150478	6,6%
13	Chierese	Consorzio Chierese Servizi	CCS	19	124903	5,5%
14	Torino Sud	Consorzio Valorizzazione Rifiuti 14	COVAR 14	19	259207	11,3%
15	Torino Ovest e Valsusa	Consorzio Ambiente Dora Sangone	CADOS	54	345078	15,1%
16	Torino Nord	Consorzio Bacino 16	BACINO 16	30	228030	10,0%
17A	Ciriè e Valli Lanzo	Consorzio Intercomunale di Servizi per l'Ambiente	CISA	38	99117	4,3%
17B/C /D	Canavese/ Eporediese	Consorzio Canavesano Ambiente	CCA	108	189019	8,2%
18	Città di Torino	Città di Torino	BACINO 18	1	896773	39,1%

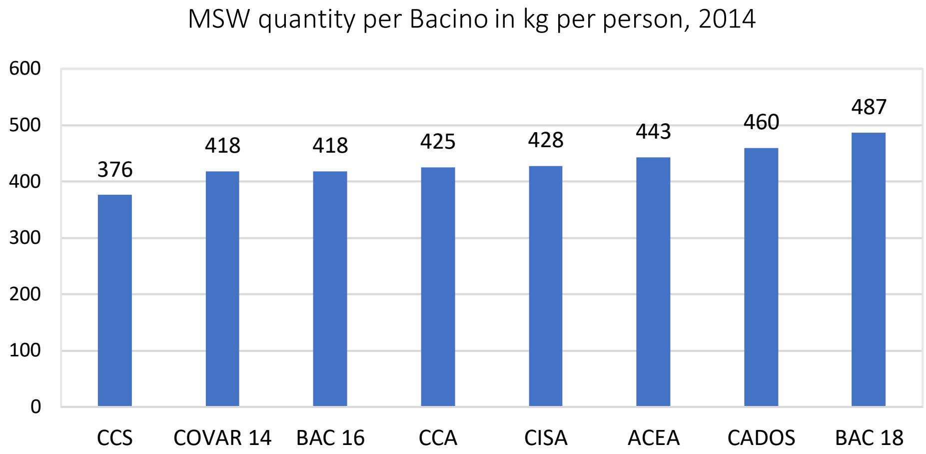
Table 2-1: Details of Bacini

Source: (Città Metropolitana di Torino and ATO-Rifiuti Torinese, 2017)

Figure 2-4: Bacini in the Metropolitan City of Turin

Source: image available at atorifiutitorinese.it

An overview and tool of comparison is provided by the following graph, highlighting the performance of each bacino taking in account the total waste produced, sorted and unsorted waste per person.



	CCS	COVAR 14	BAC 16	CCA	CISA	ACEA	CADOS	BAC 18
Sorted Waste	58%	62%	55%	53%	55%	54%	57%	42%
Unsorted Waste	42%	38%	45%	47%	45%	46%	43%	58%

Table 2-2: Waste quantity per Bacino in kg per person, 2014

Source: (Città Metropolitana di Torino and ATO-Rifiuti Torinese, 2017)

From data analysis it is possible to highlight the bacino with the lowest and higher MSW per capita:

CCS:

- It is the most environmentally friendly bacino and the only one producing under 400 kg per capita of waste;
- It produces 50 kg below the average value, saving cost and time;
- COVAR 14 is the only one with a higher sorted waste ratio.

BACINO 18:

- It is the top producer of waste, with a total amount of 487 kg per person, having an extra of 55 kg waste per person if compared with the average value;
- It has 57.7% of unsorted waste, which means an extra 100 kg of waste per person compare to the average, resulting in extra energy and work to separate recyclable material from non-recyclable, thus decreasing the rate of recyclable because of contamination;
- It is the only bacino which a higher rate of unsorted waste than of sorted waste.

Regional data collection is managed and controlled by Rete Unitaria della Pubblica Amministrazione Regionale Piemonte (RUPAR) and together with Osservatorio sui Rifiuti they are responsible to promote waste awareness in the public sharing information and with annual report to:

- Check and control targets set by national, regional, and local level;
- Evaluate the remaining disposal capability of each plant to enhance the municipal waste planning system;
- Summarise a general overview and promote information sharing of activities carried out by the Metropolitan City of Turin.

2.3 ATO Acea

With a total of 68.826 tons/year, it is the third ATO as of number of municipalities and the fifth one per population.

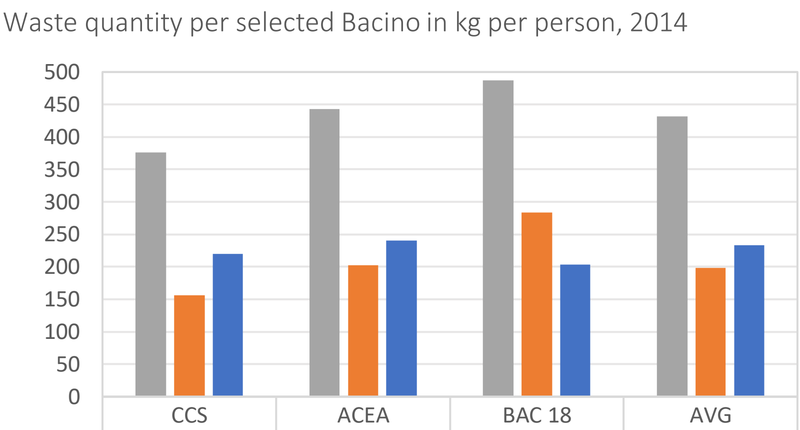
It is responsible for the collection of sorted and unsorted waste, its disposal, (pre)treatment and for the soil hygiene at the ATO level. The waste management system is based on local recycling depots, a new approach which allows to save time (compared to door-to-door) and keep a good level of recycling ratio (compared to rubbish container).

Bacini	Geographical area	Consorzio name	Acronym	Number of municipalities	Inhabitants	%
12	Pinerolese	Consorzio Acea Pinerolese	ACEA	47	150.478	6,6%

Table 2-3: Overview of Bacino Acea

Source: (Città Metropolitana di Torino and ATO-Rifiuti Torinese, 2017)

It follows an overview of the main characteristics of the ATO:



	CCS	ACEA	BAC 18	AVG
MSW	376	443	487	432
Unsorted Waste	156	202	284	199
Sorted Waste	220	241	203	233

Figure 2-5: Waste quantity per selected Bacino in kg per person, 2014

Source: Raw data available at www.cittametropolitana.torino.it

Concerning Municipal Solid Waste Acea Pinerolese is comparable with the average value of the Province, without any specific good and or bad concerns. CCS has a better sorted/MSW ratio because it produces less waste in total, yet ACEA and CSS have the same amount of unsorted waste, even if there is a gap of 70 kg in MSW.

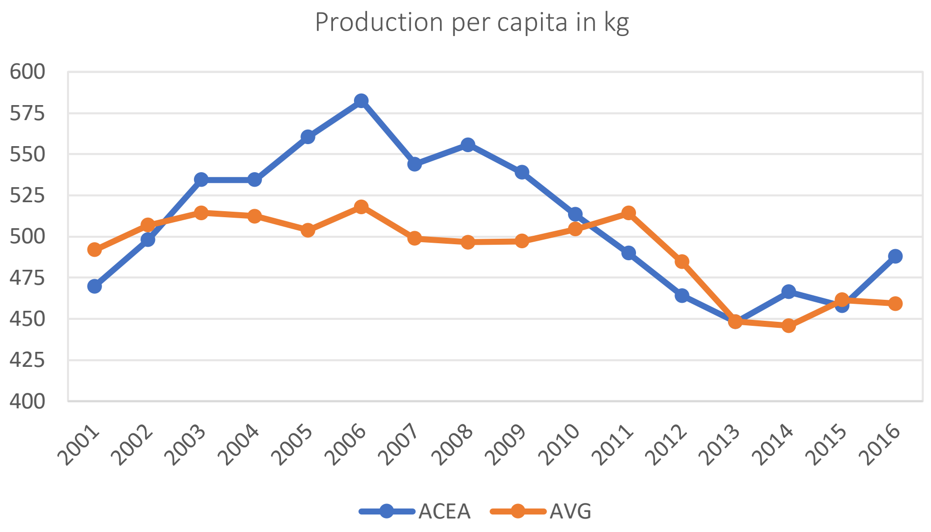


Figure 2-6: Production per capita in kg

Source: Raw data available at www.cittametropolitana.torino.it

Overall, the trend of waste production is decreasing, and only in the last couple of years has started to grow again: ACEA has surpassed the Province level by approximately 30 kg, yet the trend should decrease or stabilise according to targets set by Circular Economy principles.

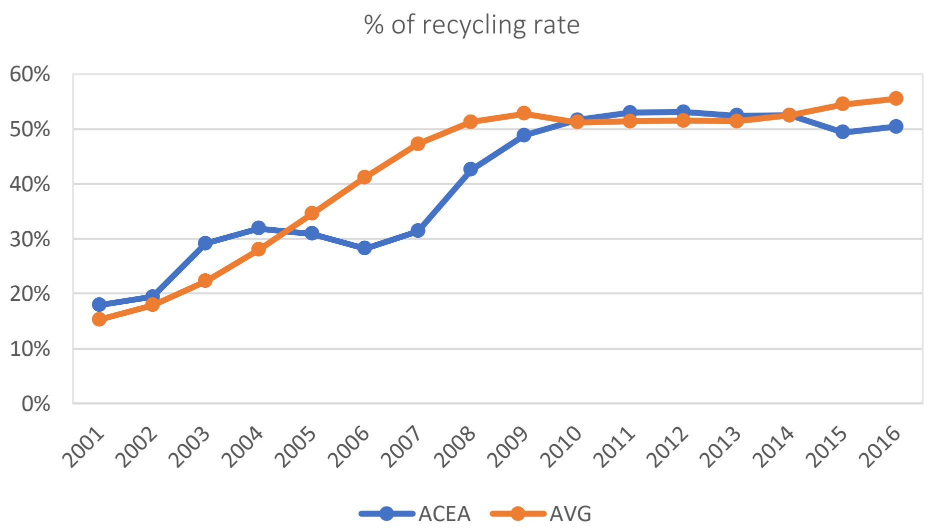
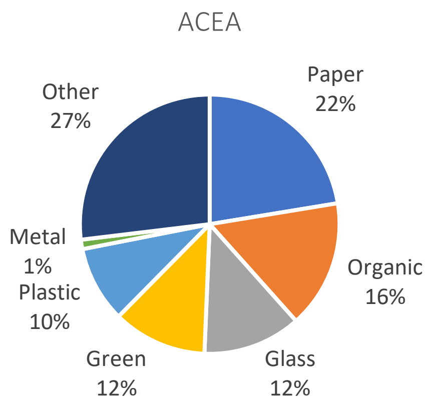


Figure 2-7: % of recycling rate

Source: Raw data available at www.cittametropolitana.torino.it

ACEA is keeping the peace on this ration, slightly below the Regional level: overall the trend is increasing, and it has already reached the target set for 2020 of at least 50% of sorted waste collected, planning to increase. Data available for 2017 and 2018 shows a stable increase of recycling rate, with an average above 55%.



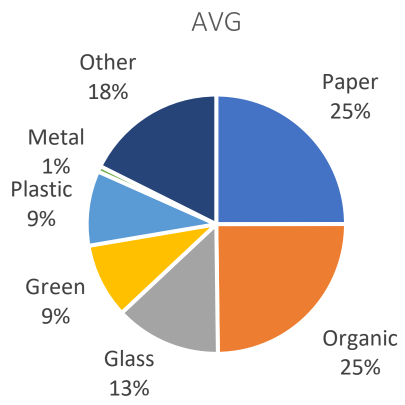


Figure 2-8: Waste composition

Source: Raw data available at www.cittametropolitana.torino.it

Waste composition is similar apart from organic and other: for Acea Pinerolese the organic fraction is less dominant compared to the AVG figure.

The next table provides a detail of waste collected per person and the recycled ratio; are highlighted in green the two kinds of waste treated directly by Acea Pinerolese; all the rest is pre-treated by the Consorzio and then disposed thanks to other companies.

Type of Waste	kg/inh collected	% recycled
Paper	46,7	99
Organic	38,2	45
Glass	29,2	95
Green waste	24,2	92
Plastic	24	71
Wood	18,9	97
Metal	3,6	100
Textile	2,1	95

Table 2-4: Collection and recycle rate for ATO Acea in 2013

Source: data available at regione.piemonte.it

As the only ATO provides a cogeneration plant for organic and green waste, Acea Pinerolese is the main operator for the Province, taking in its responsibility the treatment of 31% of total organic waste and 21% of green waste.

Flows of organic and green waste in the Province

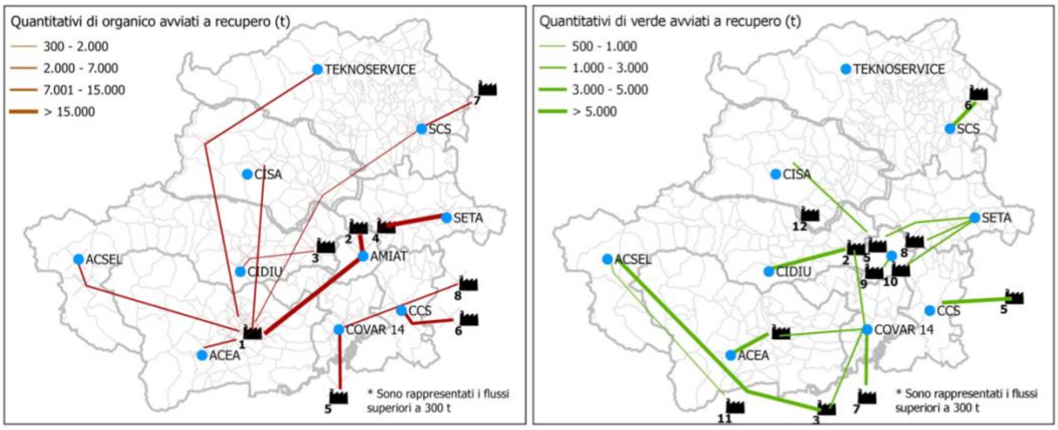


Figure 2-9: Flows of organic and green waste in the Province

Source: (Città Metropolitana di Torino and ATO-Rifiuti Torinese, 2017)

3 Chapter Three

Concepts about Waste and Disposal Practices per Waste Category

3.0 Introduction

The third chapter aims to contextualise concepts which are going to be used in this study.

In the first section waste is identified in the Life Cycle Assessment of a product or service, the best methodology practice of how to dispose is introduced and ends with an overview of the waste hierarchy pyramid.

In the last sections the focus is swift on a brief analysis of disposal practices in regard to the main category of municipal solid waste, with special emphasis on bio waste.

3.1 WASTE: LCA, ISWM, AND THE WASTE HIERARCHY PYRAMID

In the introduction the legal definition of waste has being assessed and analysed; yet, before turning into waste, every product is characterized by a life cycle which starts from raw materials, and – ideally - it should end with secondary raw materials, able to close the gap and eliminate waste. Life Cycle Assessment (LCA) is an objective technique that assess all the possible interactions and consequences between a product/service and the environment impact. LCA always ends considering the final product either as obsolete, unusable, or dangerous to use, and in any circumstance, it falls within the definition of waste.

Figure 3-1: Waste Life Cycle

Source: image from epur.fr

Integrated solid waste management (ISWM) is a systematic and strategic approach aiming to prevent, recycle, and manage solid waste with more sustainable criteria and willing to maximise resources use efficiency. It is based on four main principles:

- For public health reasons and wellness of people, a decent level of waste management system is required to contrast contaminations and provide a safer environment;
- For environment protection, the effectiveness of waste management system and its correct disposal should reach sufficient level to exclude hazardous and non-hazardous waste mix and not to contaminate water, lands, and air;
- To maximise resources usage while minimizing costs and to increase the overall efficiency and use of resources;
- For sustainable reasons from a social, economic, political, technical, environmental, and financial perspective. (Hoornweg & Bhada-Tata, 2012)

Clear targets and objectives drive a good ISMW approach, which is based on *the four R hierarchy* divided in waste diversion and waste disposal.

The pyramid also shows which options have a better impact on the environment in long terms, and which should be avoided taking into consideration financial, social, environmental, and management considerations.

Figure 3-2: waste hierarchy pyramid

Source: image available at zerowastemontenegro.me

The Waste Framework Directive (WFD) describes and defines concepts related to waste management to develop policies that protect the environment, human health, and ensure sustainable use of resources. It applies to Member States and stresses on the importance to apply the waste hierarchy for waste prevention and to deal with it in the most resource-efficient way, according to its life cycle thinking and assessment.

Waste hierarchy can be further analysed and customized on the type of waste taken in consideration; first of all: depending on how waste is collected – sorted or unsorted – different separations, approaches, and methodologies can be implemented in the life cycle of waste.

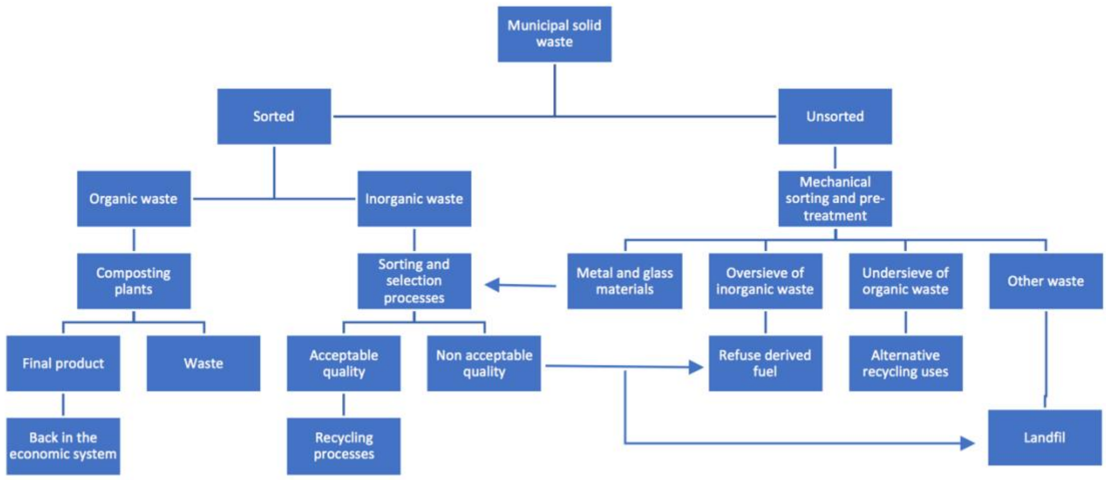


Figure 3-3: overview of municipal solid waste flow

Source: graph from rifiutilab.it

As shown in the figure above, waste can return back to the economy with different names (secondary raw material, solid fuel, recycled material) often undergoing a recycling or recovery process and it complies with one or more of the following main end-of-waste criteria:

- the substance or object is commonly used for specific purposes;
- there is an existing market or demand for the substance or object;
- the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);
- the use will not lead to overall adverse environmental or human health impacts. (Manfredi & Pant, 2011)

Let's further analyse in more details the flow of the main type of municipal solid waste: paper, glass, plastic, metal, unsorted waste, and bio waste.

3.2 Paper

Paper is one of the most common recyclable material, as up to 95% can be transformed in new raw material. Because of its composition, cellulose, it can go through multiple production cycles without losing its characteristic: this is why in 2016 72.5% of the paper consumed in Europe was recycled. (European Paper Recycling Council (EPRC), 2018)

Paper loop represents a perfect example of Circular Economy, regenerating its value and characteristics.

Recycling procedures:

- Collection and Storage: paper is first collected and transferred to a recycling plant, where it is checked and sorted in order to not include other kind of materials, and then divided into grades, types, and quality. The overall value of the future raw material increases as much as the result of this operation is precise;
- Pulping: paper is shred in small pieces and heated with water and chemicals to break it down into paper fibres;
- Screening: the pulp created is strained through screens to remove glue, adhesives, plastic film and all other remaining contaminants from previous purposes;
- Cleaning: paper is first cleaned by spinning it around cylinders, it follows a de-ink operation to remove all the possible inks present;
- Refining: the pulp is beaten to create a homogenous, de-coloured or bleached material depending on market requirements;
- Papermaking: the pulp is mixed with water and chemicals, then heated, sprayed, and pressed to create sheets and finally wound into rolls.

Generally, up to 80% of recovered paper goes through recycling processes, but some can be either mixed with other materials and it is not a standard procedure to separated them, or fibres cannot be recycled anymore. In fact, the life cycle of paper theoretically lasts from 5 to 7 recycling processes, after which fibres are no longer worth recycling; however, the average life cycle in the EU is 3,6 times versus only 2,4 times the world average. (European Paper Recycling Council (EPRC), 2018)

The main advantage of recycled paper is in term of its quality: in fact, it is possible to reach the same standards required for virgin paper. Newsprint and packaging are the top industries, using up to 93% of recycled material, while the average utilisation rate is 53%.

Other production advantages are shown in the following table:

Recycled vs virgin paper per a ton	
Raw material saved	3 tons (17 trees)
Energy saved	14 million KJ (33%)
CO2 not emitted	27 kg
Water saved	26,5 m^3
Solid waste not produced	25 m^3

Table 3-1: Recycled vs virgin paper per a ton

Source: (Waste Management, 2017)

As to cost perspective, recycled paper is very competitive for some applications, but it does not always represent the best option in terms of quality and quantity. However, mixed paper is becoming more popular as awareness is increasing in the population.

When recycling is not an option, other recovery alternatives can include:

- Re-use: products re-enter the economic cycle without any special treatments or find an alternative purpose;
- Biomass: when fibres do not meet the recycle criteria anymore, paper can be used as biomass resource without special treatments, substituting fossil fuels;
- Composting: especially for materials that are not considered sustainable for recycling, this is a better alternative to landfilling and incineration, which is also less harmful for the environment.

As it is not possible to substitute paper, actions can be implemented to reduce its usage. Governments and NGOs have developed and run campaigns to increase awareness and promoting a more sustainable approach; new policies in private and public companies promote a paperless approach and sponsor digitalization and electronic forms. Internet has reduced the amount of paper offering digital subscription of newspaper and magazines, yet, on the other hand, it has exponentially increased the ecommerce sectors, increasing carton boxes and packaging materials.

Producing recycled white paper creates 74% less air pollution, 35% less water pollution, and 75% less processed energy than producing paper from virgin fibres.

3.3 GLASS

Glass is defined as an infinitely recyclable material in a bottle-to-bottle closed loop, without loss in quality. The EU recycling rate is steady at 74%, reaching up to 95% in Sweden, Belgium, and Slovenia. (FEVE, 2018)

- Collection and storage: to be recycled, glass has to be collected, sorted by colour, and washed before going through other procedures;
- Crushing: in this phase glass is crushed in small pieces and separated from other components which can include plastics, metal, woods, and other impurities;
- Melting and moulding: glass cullet is ready to be re-melted if it falls into specific requirements of purity standards, which requires a percentage of 99,85% of glass material. As a secondary raw material, it is now ready to be melted and moulded again.

In this last phase, it is possible to mix glass with other materials to obtain a new one with specific requirements like strength increase and resiliency.

Companies have also promoted a different loop of glass, asking to their customers not to throw glass in waste containers, but to hand it back to the producers to be refurbished and directly re-filled or re-used; this is the case of some beverage companies like water, milk, and beer.

Glass does not degrade and even if theoretically it can be re-melted infinitive times, it does not stay in the loop forever.

Recycled glass requires less energy as it melts at a lower temperature, while refillable glass bottle can save approximately a third of the energy required if compared with throwaway bottles.

The main advantage of glass is that it does not lose its characteristics and purity over time. Other production advantages are shown in the following table.

Recycled vs virgin Glass per a ton	
Raw material saved	82%
Energy saved	754 thousand KJ (30%)
CO2 not emitted	34 kg
Oil saved	19 litres
Solid waste not produced	2,5 m3

Table 3-2: Recycled vs virgin glass per a ton

Source: (Waste Management, 2017)

It is an inert and impermeable material that provides the most pure and stable of all other packing materials, which is perfect for food, beverage, and health related products.

Due to its characteristics, it is very easy to separate glass from the other wastes, and its collection rate is one of the highest in the recycling industry. Thanks to public awareness, recycling rate has increased of 130% in the last 30 years; yet it still has a main limitation: in most of the countries glass is collected together rather than divided by colour: clear, green, and brown are the most common ones, and the value of the raw material depends on it, having brown as the most valuable.

When it is not convenient or needed to recycle, glass can be converted in foam glass, a material with flame retardant and insulation properties with several applications; for instance, Åke Mård, a Swedish building contractor, has transformed the foam in blocks for prefabricated buildings with the approval of the European Union. (Trentola, 2018)

3.4 Plastic

Plastic is a very versatile material, and, because of this characteristic, it is widely used for customer and industrial applications. It has light weight, it is durable, malleable, not easily corrodible, and it is electrically and thermally insulated: for these reasons plastic packaging is present in more than 50% of purchasable goods.

Unfortunately, it is a non-biodegradable product, and recycling plastic is a common practice to reduce the amount of the material in the waste stream, with an increase of over 80% in the last decade. (PlasticsEurope, 2017)

Not like glass and metal, recycling plastic has been considered not worth it, due to technical difficulties, low value of final product, and low density: to increase the overall result, plastic should be separated in categories.

Standard process to recycle plastic:

- Collection and sorting: plastic is automatically and manually sorted in different resin types, and it can be further divided by its colour;
- Shredding and washing processes: it is shredded into fragments and then washed to eliminate materials different from plastic;
- Melting: plastic is melted and extruded in granules ready to be used for new product.

PET, PE, and PVC are the most recycled polymers with technical and chemical properties similar to new raw material.

When different resins are recycled together, the recycling process is more complicated, and the final product is not homogenous, but it is still used for different purposes, like bench, playground, road signs, and fences.

27% of collected plastic is sent to landfill, 31% goes through recycling processes, while the rest is incinerated or used as fuel for thermoelectric energy.

Below some highlights in production saving in recycling processes.

Recycled vs virgin plastic per a ton	
Energy saved	5,774 kWh (88%)
CO2 not emitted	34 kg
Oil saved	2,5 litres
Solid waste not produced	23 m3

Table 3-3: Recycled vs virgin plastic per a ton

Source: (Waste Management, 2017)

Plastic can be recycled once or twice, and then it is recycled as fabric or commodities which cannot be recycled again: over time plastic breaks down in tiny parts which can be found everywhere and are harmful for the environment. For instance, plastics and microplastics in oceans represent a big challenge nowadays, becoming a major priority for governments with proposal and legislation to reduce or ban single-use plastic and replace them with more sustainable materials, especially for products like food containers, packaging, disposals and cutlery, straws, bags and similar. (PlasticsEurope, 2017)

For this reason, bioplastics is an alternative solution with similar characteristics and properties but coming from potatoes, cereals or corn. The first advantage is in its biodegradable characteristic, minimising its environment impact, reducing greenhouse gas emission, and saving fossil fuels. (NaturePlast, 2018)

Recently, *Science* has published an article about γ-butyrolactone, a synthetic polymer which can be depolymerised in starting monomers and recycled into new material. The university of Colorado has studied the properties of the polymer based on this component, defining a good strength level and light weight, potentially able to create a circular loop. (Jian-Bo Zhu, 2018)

The main aim is to minimise the use of plastic where it can be easily substituted with other alternatives, while optimising its use in industries like constructions, mobility, energy, and electronics where its physical characteristics are essential for the final product or service.

3.5 METALS: STEEL AND ALUMINIUM

Due to their physical properties, steel and aluminium are materials with application in all sectors, even their scraps have an economic value, in contrast with other waste categories, having 40% of the metallurgy sector working through recycled material.

Widely used for cans, containers and so on, recycling aluminium is essential for the metal industry because of its economic advantage. It follows the cans recycling cycle:

- Collection and Sorting: metal is collected and separated from other non-ferrous material using magnets;
- Cutting: cans are cut in pieces to decrease the total volume and to facilitate the sorting process;
- Washing: before being reprocessed, cans are washed to eliminate possible residuals;
- Re-melting: through this process, the metal molten is separated from all the impurities like coating and inks;
- Creating new material: depending on the final products, other materials can be added to increase the characteristics and properties of the final product (flexibility, resilient, strength, conductibility);
- Molten is then cast into rolling, ingots, or billets and ready to be reshaped in an improved design to use less raw material.

Aluminium and steel can be recycled endlessly without losing their properties: aluminium can save up to 95% of the energy needed for raw materials, while steel recycling processes can save up to 50% of water and more than 50% of energy by using an electric arc furnace. On average, every two cans out of three are collected and recycled, while 14 tons of steel are recycled every second. (Trerotola, 2018)

Below some highlights in production saving in recycling and new aluminium processes.

Recycled vs virgin aluminium per a ton	
Energy saved	14,000 kWh (95%)
Oil saved	6,3 litres
Solid waste not produced	7,6 m^3

Recycled vs virgin steel per a ton	
Energy saved	642 kWh (>50%)
Oil saved	288 litres
Solid waste not produced	3 m^3

Table 3-4: Recycled vs virgin aluminium/steel per a ton

Source: (Waste Management, 2017)

The secondary raw material of ferrous and non-ferrous metals have experienced a boost in 2007, when prices began to increase due to lack of resources and demand was drastically increasing.

The market was valued $90 million in 2012 for scraps used in steelmaking coming from car bodies, cast iron, pressing steel, turning and so on, reaching up to 50% of all recovered scrap metals; in addition, it contributes to conserve energy, reduce greenhouse gas emissions, and save natural resources.

Another challenge to recover metals is coming from the waste Electrical & Electronic Equipment (WEEE), which includes all the electrical and electronic products and components made of a mixture of different materials which, if not disposed properly, can become harmful for the environment. Considering an obsolete computer, it is approximately made of 20% of steel, 14% of aluminium, 7% of copper, 6% of lead, and 2% of zinc: all these metals can be recovered and reused, the only constraints are in regulations and in the recovery cost. (Chalmin & Gaillochet, 2009)

3.6 Unsorted waste

When waste is properly sorted, unsorted waste consists of all materials which do not fall in the main MSW categories: different kind of waste is collected together, compromising the level of recycling material which can be recovered. For its composition, this kind of waste is not recyclable, and it can be discarded in landfills, it can become waste-to-energy, or it can be incinerated.

From an ecological perspective, unsorted waste should be delimited just to non-recycling products, in order to reduce the amount of recyclable material landfilled, reduce energy consumption, and extraction of new raw materials.

Treatment method	Recovered products	Avoided products	Remaining waste
MBT	Biogas, refuse derived fuel, compost-like output	Electricity, heat, soil covering, recyclable materials	Stabilized waste or digestate, Residues / impurities, Recyclable materials
Incineration	Energy	Electricity, heat	Residues
Landfill	Biogas	Electricity and/or heat, legal and illegal dumping	Leachate

Table 3-5: Mixed waste collection treatments overview

Source: (Manfredi & Pant, 2011)

3.6.1 Mechanical-biological treatment (MBT)

MBT covers different processes aiming to separate biodegradable waste from a general waste mix and prepare residual to be landfilled by stabilising waste and reducing its mass and volume. Due to EU and national legislation, the amount of biodegradable waste in landfill is limited and controlled by MBT: this prevent the generation of spontaneous biogas, odours, leachate, and other pollutants.

Process:

Mechanical sorting is the first phase, where automated mechanical systems classify waste by separating recyclable material from non-recyclable one: recyclable material is further classified: if the overall quality of the material is acceptable, it is collected and sent to a recycling facility, otherwise they can be used as refuse derived fuel; while non-recyclable material is sent to landfills.

The second phase includes anaerobic digestion and composting: the first one causes the biochemical resolution of the biodegradable components of waste through microorganisms in anaerobic condition. Through this process waste is turned into biogas and leftover, which can be use in the agricultural sector. Composting requires the present of oxygen and microorganisms produce CO_2 and compost, with no biogas production.

MBT outputs are:

- Compost-like output: because of the low-quality of input material, this product does not reach the quality criteria for agriculture applications, and it is mostly used to cover landfills;
- Pre-treatment phases separate materials which can be recycled like plastic, metal, and glass;
- Anaerobic digestion produces biogas, mainly for energy purposes.

3.6.2 Incineration

Thermal treatments are plants used for waste disposal through a high-temperature combustion process, having ashes, flue gas and heat as end products. Heat can be recovered and used to produce steam for electricity production and as a heat vector: this allows waste-to-energy and justifies the adoption of this treatment. The main problem of incineration is in smoke contents, with a broad range of volatile pollutants, which must be controlled with appropriate technologies before being released.

Outputs are:

- APC residues: a mix of components separated from flue gases through treatments, which can contain: ash (fly or boiler), active coal, cleaning reaction products, and unreacted chemicals components;
- Bottom ash: it consists of all the heavy components left from the combustion; it is possible to recover some material (iron, steel, aluminium, copper, zinc) and use them as secondary raw material for road and construction sector.

3.6.3 Landfill

It is the last alternative for waste disposal; only low-carbon organic and non-recyclable material can be landfilled: in any other case, it should follow the waste hierarchy and go through a different treatment, taking landfill as the very last option and just in the case allowed by law.

Through aerobic digestion, gases like methane and CO2 are produced and released in the environment or collected to produce energy. However, there are other risks related to this practice: for example, leachate, very harmful for the soil and water if not managed correctly; to reduce this risk, waste should be treated, and landfill should follow construction rules to contain and collect it to facilitate its treatment.

Landfill is not a sustainable option for waste management practices, as benefits do not justify the downsides, plus waste is not considered as a resource, losing the opportunity to decrease the environmental impact through more efficient waste treatments.

3.7 Bio-waste

The technical definition of bio-waste is a biodegradable material coming from garden and park, households, restaurants, caterers and retail premises; it also includes comparable waste from food processing plants and other with similar biodegradability properties comparable in nature, composition and quantity. Processed food, paper, textile, manure, sewage sludge, forestry and agricultural residues fall in a wider definition of biodegradable waste and they go through different waste streams (European Commission, Directorate-General for Environment, 2015).

The following figure refers to Figure 1-2 and identify the source of Bio-waste as defined before.

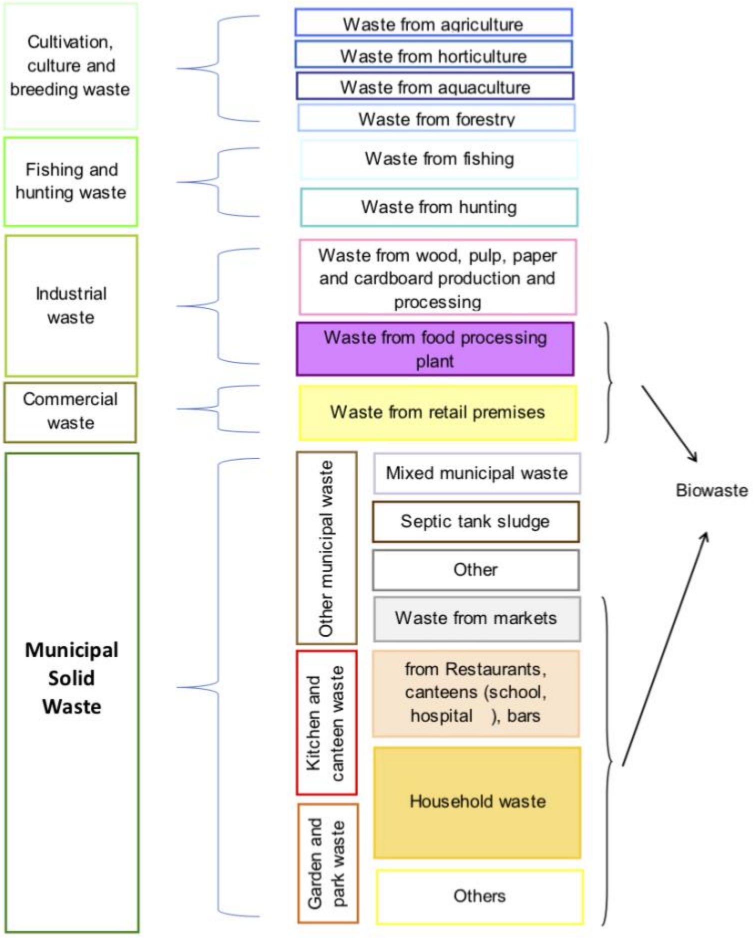


Figure 3-4: Sources of bio-waste

Source: (Manfredi & Pant, 2011)

Accounting for 46% on a world-wide scale, the European Union itself produces from 120 to 140 million tons of bio-waste, of which 70% comes from municipal waste. It is a resource with a potential higher conversion rate respect other wastes, however its potential has been taken seriously just in recent years. About 40%

of the European bio-waste is landfilled, contributing to increase greenhouse gas emissions, soil and water pollution while it reduces valuable resources.

Supporting and acknowledging the potential value of bio-waste, EU member states are encouraged to introduce relevant measures to separately collect bio-waste where technically, environmentally and economically practicable, in order to re-use and recycling them in a Circular Economy perspective.

In support to the importance of waste management in a more sustainable and environmental perspective, the European Union has recognised the potential of bio-waste, with the aim to "develop European standards for bio-waste entering organic recycling processes, for compost and for digestate, based on best available practices". (European Parliament, Council of the European Union, 2018)

Best practices are described in the Waste Framework Directive (WFD), which describes and defines concepts related to waste management to develop policies that protect the environment, human health, and ensure sustainable use of resources. It applies to Member States and stresses on the importance to apply the waste hierarchy defined before, for waste prevention, to deal with bio-waste in the most resource-efficient way and deliver the best environmental outcome. (Manfredi & Pant, 2011)

Hierarchy applied to bio-waste is as follow.

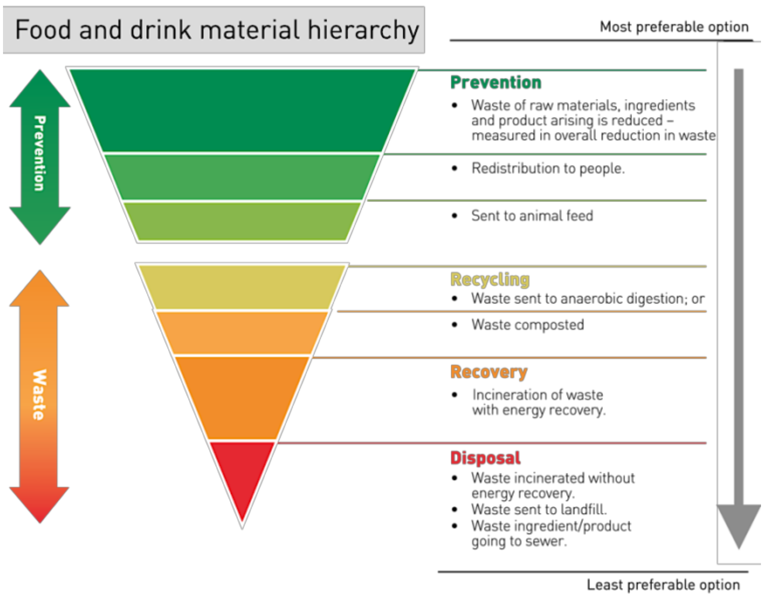


Figure 3-5: Waste hierarchy for bio-waste

Source: image available at publications.parliament.uk

In order to extend the potential of bio-waste, WFD promotes to collect and recycle bio-waste separately by introducing door-to-door collection, which speeds waste stream and increases the possibility to meet quality criteria to obtain better result from its treatment.

The quality and composition of input material will define the characteristics of the output products and its future use. Factors which influence a low-quality of output are:

- Collection of mix waste instead of mix bio-waste, increasing the level of contamination like shown in Figure 2-6;
- Material recovery operations are compromised by undersized processes or obsolete plants;
- The primary purpose of the plant is to separate organic waste before landfill.

Size Fraction (mm)	Percentage on a wet weight basis (%)				
	Glass	Metal	Plastic	Non-combustibles	Biodegradable organic matter
20.0~13.2	3.60	0.00	8.06	0.00	88.3
13.2~6.7	2.55	0.21	8.70	0.56	88.0
6.7~5.0	2.34	0.27	3.74	0.87	92.8
<5.0	4.02	0.04	0.80	0.11	95.0
Whole sample	3.08	0.16	4.34	0.46	92.0

Figure 3-6: Components in five samples of unsorted MSW

Source: (Zhang Y., 2012)

When bio-waste is collected separately the risk of contamination is low enough and the treatment methods can valorise the organic content; it can go under three main treatment methods: anaerobic digestion, composting, and pyrolysis & gasification.

Treatment method	Recovered products	Avoided products	Remaining waste
Composting	Digestate	Growing media (e.g., peat), fertilizer, conditioner	Residues / impurities
Anaerobic digestion	Biogas, digestate	Electricity, heat, fertilizer, vehicle fuel	Residues / impurities
Pyrolysis	Syngas, Char	Electricity, heat	

Table 3-6: Mixed waste collection treatments overview

Source: (Manfredi & Pant, 2011)

Other parameters which influence bio-waste treatment are:

- Quantity of bio-waste depending on economic and technical feasibility;
- Quality of bio-waste and chemical equilibrium through time;
- Treatment facilities availability;
- Need and demand of energy supply;
- Demand of product from the agronomy market.

3.7.1 Anaerobic digestion

This treatment is characterized by anaerobic conditions, where microorganisms break down biodegradable material into simpler chemical components in absence of oxygen. Because of high content of moisture, food waste and similar are particularly suitable for this treatment, while mix waste renders produce low quality final products.

Pre-treatment is always required to maximize final results: bio-waste is first unwrapped from containers and fragmented in homogenous parts. Level of moist is checked and, depending on the solid content, water or other solutions can be added. The material must be mixed to facilitate the contact between bacteria and the substrate, homogenizing the temperature and the release of the biogas and avoiding sedimentation and films formation. The process takes at least 14 days and up to a month.

Factors which influence the anaerobic digestion:	
Temperature	Higher temperature plus other parameters allow a more sterilized environment, able to destroy viruses, pathogens and seeds. This variable mainly depends by the use of mesophilic (25-35°C) or thermophilic (49-60°C);
Retention Time	It is the time required for digestion processes: the reaction rate is variable, but it decreases over time, providing better results. The longer is the retention rate, the better is the final result. This variable depends on the feedstock and other operational parameters like temperature;
pH	A pH of 7 optimizes the anaerobic digestion, while other values could inhibit chemical reactions;
Ammonia concentration	It is a critical parameter, with a range between 20 and 30 ppm;
Mixing	Good mixing is required for homogeneous optimal process conditions;
Other parameters include	Water content, Redox conditions, content of lignin in waste.

Figure 3-7: Factors which influence the anaerobic digestion

Process:

- Hydrolysis: complex organic molecules are broken down into amino acids, simple sugars, fatty acid;
- Acidogenesis: remaining components are further breakdown by acidogenic bacteria through fermentation, obtaining VFAs, carbon dioxide, ammonia, hydrogen sulphide;
- Acetogenesis: the breaking down process continues by using what is left and obtaining acetic acid, hydrogen, and carbon dioxide;
- Methanogenesis: it is the last stage of anaerobic digestion where by-products of previous phases are transformed in methane.

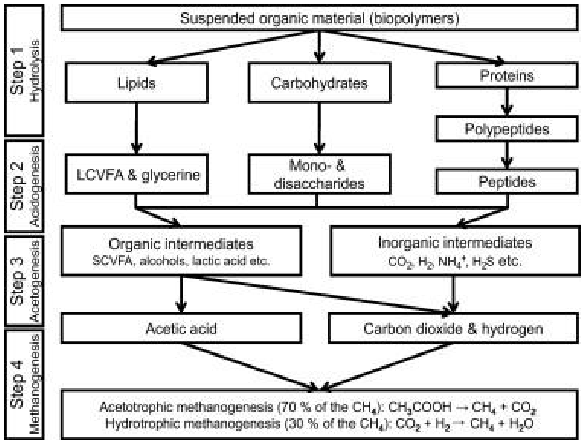


Figure 3-8: Anaerobic digestion process

Source: (Michael Madsen, 2011)

The principal output of anaerobic digestion is biogas, digestate, and water.

Biogas: it is the final product of the reaction. It is made of methane, carbon dioxide and water, yet it is possible to find low level of hydrogen sulphide which has to be removed from the gas to preserve its quality. It can produce electrical and thermal energy. Since the gas is not released directly into the atmosphere and carbon dioxide derives from an organic source with a short carbon cycle, biogas does not contribute to the increase of CO2 concentrations in the environment and it is considered as a renewable energy source with a low environmental impact. Biogas production can be continuous, if new material is constantly added, or in batch.

Digestate: it is the remains of the process and, depending on its composition, it can be used directly as fertiliser or after it has been composted. In the second case, the digestate is stabilised and sanitised to minimise toxic level and prevent soil contamination; while in the first case its use in the agricultural sector is still contradicted.

Water: it comes from moisture present in bio-waste and as a product during the digestion phase, and it goes through other treatments before being released or reused.

3.7.2 Composting

It is an aerobic process that transform bio-waste into soil/compost and fertilizer thanks to microorganisms, fungi and oxygen. Through this practice, compost is stabilized with oxidation and fermentation processes, and sanitized as the process releases a considerable amount of energy as heating reaching 55-70°C.

Pre-treatment phase is essential to define the final product: this includes waste separation from other municipal solid waste if it is not collected separately. The quality of bio-waste mechanically separated from MSW does not reach sufficient level for agricultural purposes, as the risk of contamination is too high. The next step is to create a homogenous mixture by a shredding process.

The first phase of the process involves high activity of microorganisms which break down complex molecules through hydrolysis of degradable components, and it generally lasts for few weeks

In the second phase, less degradable fraction is collected and humified to facilitate the process, and it can last from two to three months.

Composting produces the most gaseous emission, including CO2, methane, ammonia, and nitrous oxide, which can be controlled with bio filters.

Industrial composting allows optimal control of the process conditions (humidity, oxygenation, temperature, etc.) and the presence of possible pollutants in raw materials (for example residues of heavy metals and various aggregates) or pathogenic microorganisms for agriculture. Mechanical separation and biological treatments allow to increase the overall quality of raw material.

Factors which influence the composting process:	
Porosity	To guarantee aerobic digestion, porosity has to be around 35% for an adequate passage of air and oxygen; under this level anaerobic digestion is increased together with production of ammonia, hydrogen sulphide and other substances. This parameter can be controlled by adding green parts (leaves, mowing, trees branches) which allow less compaction.
Oxygen	To favour the proliferation and decomposition activity of aerobic bacteria, oxygen level must be between 5 and 10%.
Moisture	Especially in the initial phase, its moisture level must range from 55 to 70%.
pH	It tends to acidify during the decomposing process, yet it should be kept 6 and it can be controlled by adding substance like ash, calcareous substances, or marine algae.
Other parameters include	Nature of waste input, contaminations, living condition for other organisms.

In waste management, composting is an interesting form of disposal and recycling for the following reasons:

- It allows the disposal of biodegradable components, with recovery of material and reduction of environmental impact;
- It avoids unwanted phenomena that could take place in landfill waste treatment like biogas production, leachate, odours;
- It allows the treatment organic fraction of waste which contains considerable quantities of water and consequently limits its possibilities of use;
- It allows to use completely the organic fraction without producing any by-products to be disposed of;
- It does not require energy input;
- The final result is the production of compost.

3.7.3 PYROLYSIS AND GASIFICATION

Both are able to transform waste into energy through thermal processes, providing greater energy recovery than traditional incineration plants.

Pyrolysis is a thermochemical decomposition process of biomass through heat at a temperature ranging from 400 and 800°C, in absence of oxygen and under pressure. Depending on the level of carbon in the waste stream, the efficiency of the process increases: because of this, bio-waste provides better results and it is important to separate waste and avoid non-organic components to create a homogeneous input material.

Outputs are:

- Biochar: it is a solid residue and it represents 20-30% of the input weight and contains high level of carbon which allows its use as fuel with a calorific value of 8000 kcal/kg;
- Liquid residue: 50-60% of the input turns in an oily fraction made of water, tar, and other organic compounds but its composition depends on the waste treated;
- Gas residue: 15-30% of the input, this gas is made of hydrogen, carbon monoxide, carbon dioxide, hydrocarbons and it has a medium-high calorific value (12-22 MJ/kg).

Gasification requires oxygen and higher temperature (800-1100°C) than pyrolysis and it can operate with solid chart from the first process.

Outputs are:

- Syngas: it a fuel gas made primarily of hydrogen, methane and carbon monoxide with a calorific value of 4 to 6 MJ/Nm^3; it is considered a source of renewable energy with a lower impact that burning input biomass;
- Char: solid residue for construction material or to dispose.

These technologies are not widely used for technical challenges but are expected to be developed and implemented in the future.

4 CHAPTER FOUR

CIRCULAR ECONOMY AND ITS CORRELATION WITH WASTE

4.0 INTRODUCTION

Until now waste level, its composition, and best practices have been described starting from a world overview and narrowing down to Europe, Italy, Piedmont, and ATO Acea, with a special regard to bio-waste.

From this chapter on, the study is going to focus on a different perspective, considering waste as an alternative source of resources instead of a problem to solve.

After a comprehensive overview of what is meant by Circular Economy and comparing it with the linear system, the focus is going back on bio-waste and its potential by introducing a model of Circular Economy further investigated in Chapter Five.

4.1 WHAT IS MEANT BY CIRCULAR ECONOMY

From this chapter on, our analysis is going to focus on a different shape, considering waste as an alternative source of resources instead of a problem to solve. Yet, this is not a new idea: in fact, concepts along this topic include terms like sustainability, environment friendly, eco-friendly, biodegradable, sustainable development, green economy, bio economy and so on.

The aim of Circular Economy is to change the perspective on how people produce, consume and dispose by creating new value from what it is already available, without basing the need on new resources. The main difference from concepts mentioned before, is its comprehensive application in the LCA of a product/service with tangible results in the economy, applicable on every product/service of any sector.

This "closing the loop" idea is the concept behind the circular approach to achieve an economically and environmentally sustainable growth, attracting the interest of public, non-profit, and private sectors to start a cooperation by studying, modelling, and sharing information and know-how to speed the transition to a more circular mentality.

Taking Europe as an example, the implementation of a Circular Economy has made the European Commission withdraw the legislative proposal on waste in 2015 because targets were not ambitious enough and the idea of closing the loop was not the centre of the discussion. The attention was then focused on new targets, but also on responsibility, reporting obligations, streamline definitions and calculation methods to track targets, creating and defining the Circular Economy Package. (Bourguignon, 2016)

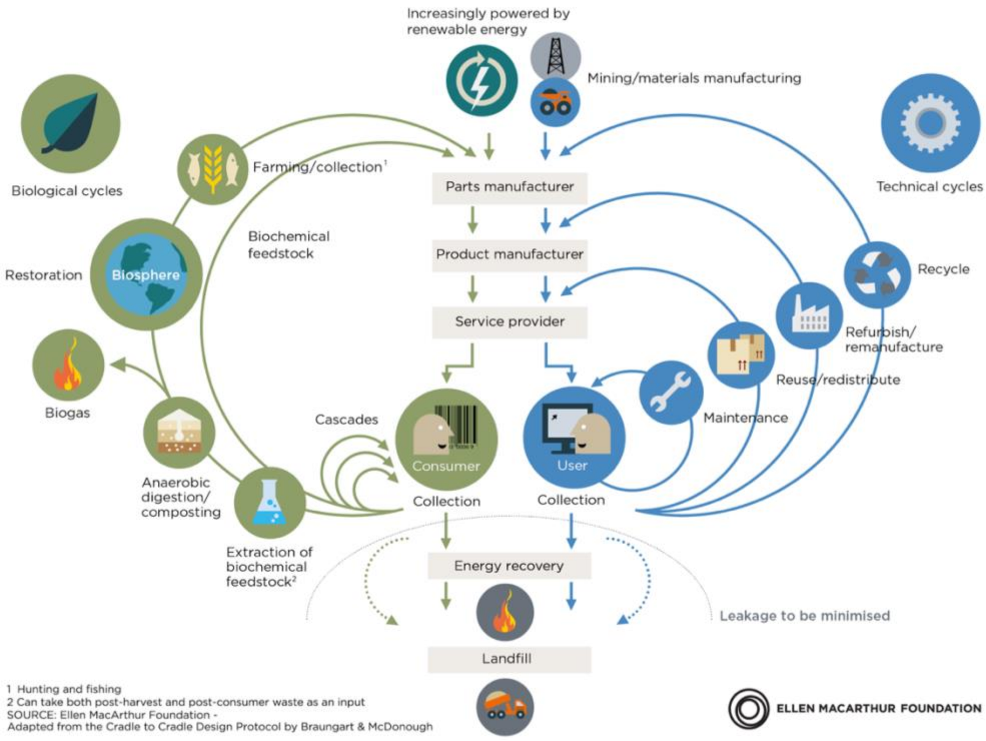


Figure 4-1: CIRCULAR ECONOMY – an industrial system that is restorative by design
Source: Ellen MacArthur Foundation circular economy team drawing from Braungart & McDonough and Cradle to Cradle (C2C)

4.2 LINEAR VS CIRCULAR ECONOMY

As an evolution of the traditional linear economy, Circular Economy is a model aiming to extend the life cycle of a product and materials, by changing the way a product is designed, used, and disposed.

The linear economy is based on the idea that an increase of production requires more resources and, eventually, more waste. Take, make and dispose are the only variables considered: taking the materials and resources needed to make goods, making a profit, then disposing when the need is no longer satisfy. This approach has been sustained by globalisation and the abundance of cheap materials compared to human labour, discouraging recycling and reusing, especially in developed countries, which has been and is associated with pollution and non-environmentally friendly.

Criticisms started to raise when other countries have started to become more competitive regards to the demand of raw material: for this reason, prices have begun to raise with no limitation. China and India, defined as fast economic development countries, have changed the market, its economic rules and habits of people, which have started to use and dispose of more products.

Due to global economic evolution and expansion, the Global Footprint Network has calculated that it would take a year and a half to produce raw material and absorb all the waste consumed in a year; the United Nations denounced that we would need two Earths by 2030 and three by 2050 if the current trends do not change. Both organisations highlight the main limit of linear economy: resources are not able to follow human needs, especially if demographic trend keeps on growing. It is not possible to deny economic and human development and resources are limited in amount, it has to change the approach and mentality behind it, by adding new regulations and emphasising different priorities. (Bonciu, 2014)

The term *Circular Economy* indicates an economy where "the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised" – doing more with less, and it is one of new perspective presented. Included in the 7th Environment Action Programme, the concept of Circular Economy aims at promoting a sustainable growth by improving resource efficiency, considering new material and turning waste into alternative resources. (European Commission, Secretariat-General, 2015)

It acts and supports along with other principles and targets like sustainable development, green economy, climate change, low carbon economy and so on. It is a feasible concept which works with already available information and does not need new or extra technologies, but a change in the way of thinking.

In the circular perspective, raw material still comes from the environment and it does not exclude the production of waste, which would not be possible; rather waste or part of it is turned into a resource and indefinitely recycled in an ideal perspective. In a more realistic perspective, waste is kept in the economy as long as it has a potential and then is disposed following the waste hierarchy and minimizing its impact on the environment. It is defined as a perspective because it provides guidelines and promotes the use of best practices, rather than giving instruction on how to save the planet. It focuses on optimising the system not components, making a clear distinction between the use of material and its consumption. (Bonciu, 2014)

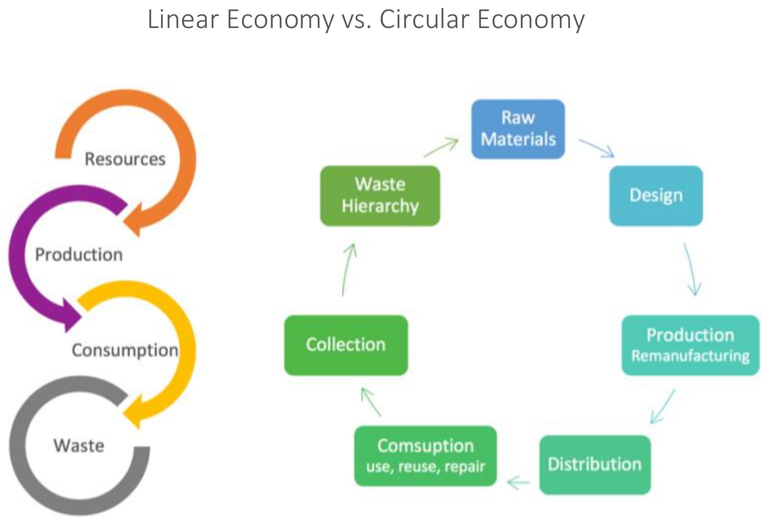


Figure 4-2: Linear Economy vs. Circular Economy

Source: (Bonciu, 2014)

What distinguishes Circular Economy from previous approaches are the following aspects:

1. Holistic approach: every product or activity of a sector is taken into consideration in the Circular Economy approach. Considerations are made on the life cycle of a product, starting from raw materials and the design of a product, service or process in order to allow a longer life cycle and an alternative use/application at the end of its life cycle. An example can be discouraging the purchase of new product by increasing its level of reparability and durability;
2. Synergies and scalability: by stimulating collaboration between industries and by a standardisation of rules it would be possible to create an efficient and large economic system, based on resource exchange without losing any alternative use of waste. In term of scalability, it would allow to reduce raw materials and to save energy if implemented on a national or union level;
3. Legislation and framework: on a European level, the need of change is a first priority and actions have been taken to cover social and economic aspects;
4. Performance indicators: to monitor Circular Economy implementation and progresses, performance indicators are required and have to be applied homogeneously and correctly by all the countries to obtain a correct overview and to develop correction actions.

4.3 SWOT ANALYSIS OF CIRCULAR ECONOMY

SWOT analysis is a tool which helps evaluate what are the strengths, weaknesses, opportunities, and threats of a Circular Economy: the first two parts of the SWOT analysis helps to identify the main advantages and the main criticisms, both essential to understand the main advantages and the areas to be improved.

Opportunities can highlight future ways to increase the adaption rate and new realities; while threats describes the main limitations, which can occur and limit the final result, and thus the overall succeed of circular economies.

In the following figure the swot analysis for Circular Economy is described.

Figure 4-3: swot analysis per Circular Economy

Source: (Sariatli, 2017)

4.4 The EU and the Circular Economy

The European Union has strongly affirmed the need to change to a more sustainable approach, especially as regards of waste management; in the *Manifesto for a Resource-Efficient Europe* the European Commission states: "In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative Circular Economy […] which could lead to steady economic growth with business opportunities across the whole economy." (European Commission , 2012)

The concept has been enhanced and promoted through new legislations, new directives, the development of a EU strategy and EU action plan for the Circular Economy, with a monitoring framework on progress, and with regular reports to monitor every industry and sector related. The transition to a more sustainable approach has been seen as an opportunity to reinforce its competitiveness and become more independent by strengthening the EU main weakness: its lack of natural resources. In fact, as a major importer of resources, the EU has always needed the cooperation and support of other countries to keep its production stable but, in the contest of the Circular Economy, the role of external providers becomes less relevant by exploiting and adding value to secondary raw materials already available in the production system: this would lead to a steady growth enhancing business opportunities, innovation, and the creation of new jobs. (European Commission, 2015)

In order to include as many countries and companies as possible, the EU provides guideline and guidance and it promotes the share of information, know-how, and best practices case between all stakeholders through online platform like European Circular Economy Stakeholder Platform and the European Resource Efficiency Platform. It is described as a win-win situation, which would be able to save at least 8% of the EU business annual turnover, to generate more than 500.000 new jobs (one third from the waste management alone), and to reduce the carbon emission by 450 million tons by 2030. (European Commission, 2015)

Targets and achievements are essential for the European Commission to follow its development and implementation rate and are always under review. Circular Economy targets are defined and described in the following four legislative proposals: *Waste Framework Directive*; *Landfill Directive; Packaging Directive*; *Directives on end-of-life vehicles, batteries and accumulators, and waste electrical and electronic equipment;* while the *Action Plan for the Circular Economy - Closing the Loop* aims to promote and communicate the Circular Economy idea. Circular Economy targets set to preserve waste potential are as follows:

- Ability to provide economic instruments to minimise waste disposal;
- Standardize methods for recycling rates calculation throughout the EU;
- Develop and enhance product re-use and industrial symbiosis;

- Increase market share of greener products, while supporting recycling systems. (European Commission, 2018)
- Waste management targets as follows:

Waste Management Targets in %	By 2025	By 2030
Municipal waste prepared for reuse and recycling	60%	65%
Municipal waste landfilled	-	10
All packaging waste prepared for reuse and recycling:	65%	70%
Plastic packaging waste	55%	-
Wood packaging waste	60%	75%
Ferrous metal packaging waste	75%	85%
Aluminium packaging waste	75%	85%
Glass packaging waste	75%	85%
Paper and cardboard packaging waste	75%	85%

Table 4-1: Waste Masnagement Targets in % by 2025 and 2030
Source: (Bourguignon, 2016)

In order to measure achievements and targets, performance indicators have been developed: all indicators have been developed according to actual data availability, and results are already available in the Circular Economy section on Eurostat website.

The EU has defined four broad areas to monitor through 10 indicators, which are further split in sub-categories:

Production and consumption:

1. EU self-sufficiency for raw materials: the share of a selection of key material (including critical raw materials) used in the EU that are produced within the EU;
2. Green public procurement: the share of major public procurement in the EU that includes environmental requirements;
3. Waste generation: generation of municipal waste per capita; total waste generation per GDP unit and in relation to domestic material consumption;
4. Food waste: amount of food waste generated and its impact on the environment, climate and economy. Still to develop;

Waste management:

5. Overall recycling rates: recycling rate of municipal waste and of all waste except major mineral waste;
6. Recycling rates for specific waste streams: recycling rate of overall packaging waste, plastic packaging, wood packaging, waste electrical and electronic equipment, recycled bio-waste per capita and recovery rate of construction and demolition waste;

Secondary raw materials:

7. Contribution of recycled materials to raw materials demand: secondary raw materials' share of overall materials demand – for specific materials and the whole economy;
8. Trade in recyclable raw materials: imports and exports of selected recyclable raw materials

Competitiveness and innovation;

9. Private investments, job and gross added: private investments, number of persons employed, and gross value added in the Circular Economy sectors;
10. Patents: number of patented new technologies related to waste management and recycling.

New methodologies and relevant data collection are key elements to improve and better capture Circular Economy implementation is the EU. (European Commission, Directorate-General for Environment, 2018)

Monitoring the effects of the Circular Economy is important as much as monitoring the transition process: through this second point, it is possible to know how a more Circular Economy is perceived by industries, if there is a need to adapt regulations or to remove barriers to accelerate the process and reach better results in the long term. For instance, with further analyses, it would be possible to understand why small and medium enterprises (SMEs) are less likely to become more resource efficient compared to large company, in order to provide specific founds to accelerate the transition.

The presence of barriers depends on the country, its willingness to promote a Circular Economy instead of a linear one, and higher legislations and directives from higher institutions like the European Union. (Kirchherr, et al., 2017)

Possible barriers can include:

- Cultural barriers: the concept of Circular Economy is not properly defined or there is not willingness to try;
- Technological barriers: technologies are not available, or the cost is not comparable to benefits;
- Market barriers: there is no market request or business models are not viable;
- Regulatory barriers: policies are not available or not focused on a Circular Economy transaction.

4.4.1 ITALY AND THE CIRCULAR ECONOMY

Italy has embraced the Circular Economy approach promoted by the European Commission, and it has started to develop legislations and reforms to achieve a more sustainable approach, defining its position in November 2017 with the publication of *Verso un modello di economia circolare per l'Italia - Documento di inquadramento e di posizionamento strategico*, which provides to provide a framework and defines a strategic positioning on the topic.

In order to implement the Circular Economy in Italy, the following points represent priorities to implement:

- Revision of the legislation to facilitate the adoption of the Circular Economy, by improving consistency, simplifying processes, optimizing the environmental governance and removing obstacles for the implementation of the legislation itself;
- Identification of economic tools to encourage the adoption of circular and sustainable production and consumption models, promoting the transition to environmental tax reform;
- Spread communication and awareness to promote collaboration among all the actors involved;
- Promotion of new management models and R&D to foster innovation and competitiveness in the industrial sectors to respond to the new needs of the Circular Economy;

Within this context, the measurement becomes an essential requirement to enable concrete actions and measure results, to better communicate achievements. For this reason, national indicators have been developed for micro (enterprise, company, municipality), meso (industry, region, metropolitan area), and macro level (nation) considering the quantity of resources and their economy value. The idea behind is to give the opportunity to SMEs to better express their needs without being behind bigger competitors, focussing on the need to avoid a generalization of indicators from a national model, instead of identifing indicators capable of measuring the specific circularity of a company, a sector, a region. A first draft of them has been published, yet they are subject to continuous improvement and influence by the public and private sector.

Each level has been analysed with regard to the 5 main pillars of the Circular Economy: input, product as a service, share/rent/rental and its use, service life, and output; furthermore, for each pillar indicator details and availability have been described and also if it is meant to measure the circularity of the resources or of the economy. (Ministero dell'Ambiente e Ministero dello Sviluppo Economico, 2018)

Projects which have already been implemented concern:

- Eco-design: to promote eco-innovation for products, processes and services and innovative ecological design (for durability, recyclability, reparability and environmental and social sustainability), researches aiming to extend the life cycle of products are strongly supported;
- WEEE: promoting alternative uses of electrical and electronic equipment, or new technology able to reduce, reuse, and recycle this kind of waste;
- Industry 4.0: digital technologies are enabling factors for the transition to a Circular Economy model, allowing to collect data and generate information, know-how, alternative; it will concern the entire production system, going to enable the design and management of integrated production and de-production, making industrial symbiosis possible. (Ministero dell’Ambiente, 2017)

4.5 Bio-waste as a resource in the Circular Economy

The Circular Economy concept is often associated with the biological cycle in correlation with the law of thermodynamics: with the first law we accept that energy cannot be created or destroyed but it can be transformed, while with the second one we accept that, in order to transform energy, external energy has to be the input of the process. Following these assumptions, the concept of full recycling and zero emissions is feasible if involves carbon-based organic materials only, as it follows the carbon-oxygen cycle. In all the other cases, there is a need of a wider definition to accept exceptions. (Čiegis & Čiegis, 2008)

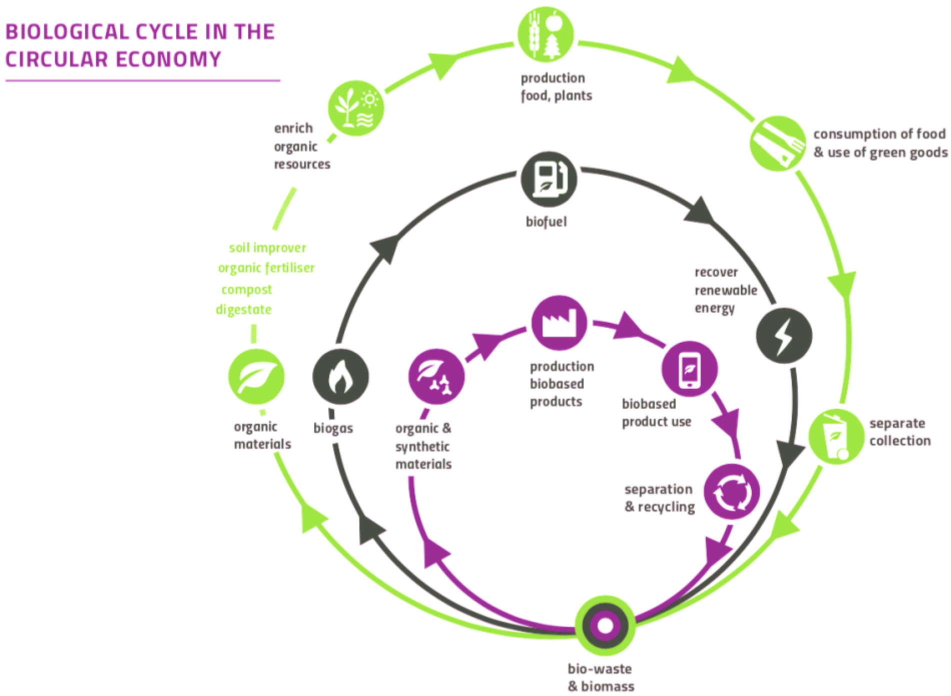


Figure 4-4: Biological cycle in the Circular Economy suggested by the European Compost Network

Source: image from (European Compost Network, 2017)

Bio-waste comprised up to 50% of MSW in the EU, of which 75% was landfilled in 2016: for this reason, it is worth to analyse its correlation with the Circular Economy because, as described before, the potential of bio-waste can be recovered and transformed in alternative resources. (European Compost Network, 2017)

Ideally, as described by the Circular Economy, bio-waste should not consider landfill as an option, as it is always present a better alternative with minor impact on the environment like anaerobic digestion, composting, and gasification; however, landfilling is still an option and it depends on the nature and quality of the waste.

Recycling of bio-waste contributes significantly to Circular Economy objectives:

- It disincentives linear economy practices like landfilling and incineration;
- The biological material loop is closed by using bio-waste as fertilisers for new raw material;
- Other sub-product can substitute less environmentally friendly fossil-based products;
- It stimulates local economy with the creation of new jobs and opportunities;
- It sets the basis to enhance separation and collection of waste. (European Compost Network, 2017)

From an energy point of view, bioenergy represents the most stable source of energy compared with other renewable source, because it is possible to predict its demand and control its supply.

In the following chapter the case study of Acea Pinerolese is going to be presented as a model of Circular Economy acknowledged by the European Parliament in 2018 and by Thornton with the "Good Energy Award 2016".

In 2003 Acea Pinerolese becomes a public limited company that has heavily invested in research and development to valorise its waste treatment practices to manage the growing amount of waste. With a global approach it aims to reconcile the needs of local municipalities with the objectives of energy efficiency, profitability and nature protection.

Polo Ecologico Integrato (Integrated Ecological Pole) is one of the first in Italy to deal with separation, process and transformation of organic and biodegradable waste. It was a hidden pearl of technology, which is now taken as an example of best practices with regard to Circular Economy at world level: the city of San Francisco, Spain and China have taken Acea Pinerolese as an inspiring example of best practices and know-how in a Circular Economy perspective.

It has received awards and acknowledgements from national and European institutions, allowing to encourage similar approach and create new cooperation and projects to further increase the circularity approach and the valorisation of waste.

5 CHAPTER FIVE

A CASE STUDY: POLO ECOLOGICO OF ACEA PINEROLESE

5.0 INTRODUCTION

This chapter presents the case study of Acea Pinerolese through a description of its Polo Ecologico.

The first section aims to provide all the information needed to make the reader understands the context of this study.

The last section presents the practices adopted by Acea Pinerolese, with a focus on the processes developed, the flow of material and the output obtained by the company in 2015.[3]

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[3] All the information presented is available at ambiente.aceapinerolese.it and aceapinerolese.it

5.1 POLO ECOLOGICO IN DETAILS

Acea Pinerolese Industriale SpA is a corporation operating with a cogeneration plant in three main areas: energy, water and waste, environment.

The Polo Ecologico core advantage comes from its technology and the synergy of different plants in a single integrated plant of 19.000m^2, which minimizing land use, transportation, and inefficiency is able to save 76.000 tons of CO_{2equ}.

The Polo includes:

- Anaerobic Digestion Plant: maximum capacity of 60.000 ton/year or organic fraction, with plant extension will reach 90.000 ton/year;
- Composting Plant: 20.000 ton/year certified with ISO 14001 and 9001;
- Photovoltaic system: 630 solar panels generating 112KW;
- Depuration Plant or Wastewater Treatment Plant: water treated for 75.000 inhabitants plus 60.000 Mg/year of drain out water from the Polo Ecologico;
- Landfill: about 3.670 m^3 certified with ISO 14001;
- Line of Refuse-derived Fuel Production: limit at 31.000 ton/year, end of activity in March 2018 redirecting waste to a waste-to-energy plant.

Operating since 2003, it is a one-stage waste treatment plant with a thermophilic anaerobic digestion stable at 55°C, which required an initial investment of €16,6 millions with an annual turnover of €6,3 millions.

The Group processes 60.000 tons of organic waste every year, the equivalent of a million inhabitants, and 20.000 tons of wood and agricultural waste, able to produce 46GWh of total energy, and it is able to heat through teleheating 2500 houses and produce electricity for 5700 houses. However, 10,4 GWh/year of electricity are used for the plant itself with another 6,3 GWh/year of thermal energy, selling the surplus to the public. (Acea Pinerolese, 2015)

Figures for 2015	Actual Capacity
Bio-waste capacity	60.000 ton/year
of which Green waste	20.000 ton/year
Total Compost produced	6.000 ton/year
Total Biogas produced	10.241.500 Nm^3/year
Total Electricity produced	17,1 Gwh/year
Of which available for the public	6,7 GWh/year
Total Thermal energy produced	18,8 Gwh/year
Of which available for the public	12,5 GWh/year

Table 5-1: Figures for 2015

Source: (Acea Pinerolese, 2015)

5.2 Flows of Material in the Polo Ecologico

Synergies and integration generated by the Polo can be described through three flows:

- Water flow: water remains from the anaerobic digestion, composting plant, and landfill are discharged into the depuration plant in order to supply treated water back to the Polo;
- Sewage flow: coming from the depuration plant, it is the first component of composting plant together with other composting material from the anaerobic digestion.
- Biogas flow: gases originated form the three plants are stocked together in the gasometer for cogeneration or combined heat and power;

5.2.1 Input of Material

As it is possible to see from Annex 1, in 2017 the input was 51.801 tons of organic waste, 9.208 tons of green waste, 2.694 tons of sewage, while the amount of water is not declared. The total energy required amounts to 16,2 GWh, of which 8,7 GWh are consumed as electricity while the other 7,3 GWh are consumed as thermal energy. (Città Metropolitana di Torino and ATO-Rifiuti Torinese, 2017)

5.2.2 Process and Flows of Material

Anaerobic and aerobic digestion explanation and the following graphic representation (Figure 5-1) of the process are available at *Mainero, 2010* and *Acea Pinerolese, 2015*.

From Waste to Mixture

In the first stage, the organic waste collected in bags is stored in a pool (1) and, thanks to a walking floor, the bags go through a mechanical pre-treatment: first, through a first grinder or bag cutter (2) and then through a sifting process (3) where organic material is separated from non-organic and ferrous material, which represents the main waste material of the digestion.

In the following stage (4), organic material goes through the Florawiva MORE™ process owned and developed by Acea Pinerolese: to obtain a homogenous mixture, water and sewage sludge are added and further filtered to detect any non-compliant material. The mixture is made of just 10-12% of dried solid waste and stored in a storage tank to reach proper conditions before the next stage.

Stage (5) consists of a thermophilic anaerobic digestion at 55°C and it lasts an average of 14 days, where the mixture goes through a mechanical stirring and biogas is captured with a recirculatory system. Digesters have a total capability of 2600 m^3 and are not heated, but insulated to avoid heat dissipation, obtaining biogas (6), digestate (7) and inert material as main results of the process.

Biogas goes through cogeneration or upgrading processes, depending on demand.

From Cogeneration to Electricity

In this case, biogas from (5) is stored in a 3300 m^3 gasometer (8) with a similar one produced by the landfill and the depuration plant; then gas is thermal treated to cool it down and compressed before being processed by three otto cycle engines generating electricity (10). Heat is collected from exhausted smokes and an engine cool-down system for thermal energy purposes (11).

From Upgrading Process to Biomethane

In this second case, biogas goes through an upgrading process (12), consisting of compression, cooling down, washing and filtering of the gas, which provides biomethane as the final product. Especially the washing and filtering phases are necessary to reach standard level of components, having at least 95% of methane, to feed biomethane into pipelines or use it as an alternative source of traction fuel.

From Digestate to Compost

The digestate is collected from the digester, dehydrated before it goes through stage (13), where it is mixed with green waste and sewage sludge to obtain a higher quality product. After, the mixture goes into a close system with accelerated maturation / bio-oxidation process (14), where air plays a key role in an aerobic digestion: air is sucked and filtered with biofilters to collect biogas.

After a month, through slow maturation / mineralization process (15), which lasts for about two months, and a final filtering process (16), the final product is available as high-quality compost sold as Florawiva compost.

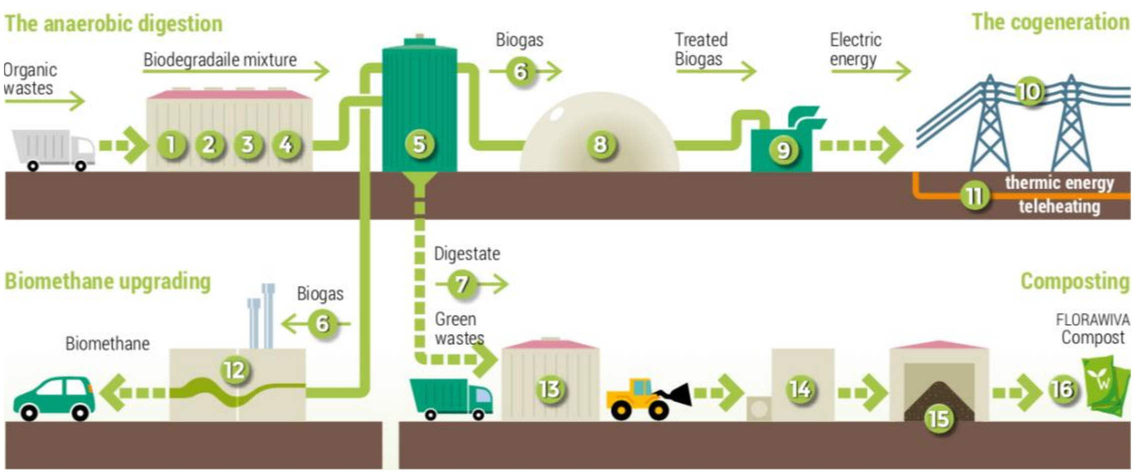

Figure 5-1: Processes developed by the Polo

Source: (Acea Pinerolese, 2015)

The depuration plant

The depuration plant has been designed to limit the use of clear water: in fact, water is extracted from sewage of the digester, the composting site, and the landfill, and treated in the water depuration plant to provide clear water for the anaerobic digestion process with a mesophilic digester. Even in sewage treatment it is possible to obtain biogas depending on the process.

Landfill

Located 3km away from the Polo, it is a complementary part of the system, helping to dispose leftover products and properly dispose other kinds of waste, like organic waste mixed with non-organic one. Unsorted waste is treated through an MBT system to reduce the volume of material going directly to the landfill: in most cases, Acea Pinerolese pre-treats waste before sending them to other recovery plants; otherwise they go through an aerobic process, which produces smokes containing biogas that is filtered and collected in the gasometer.

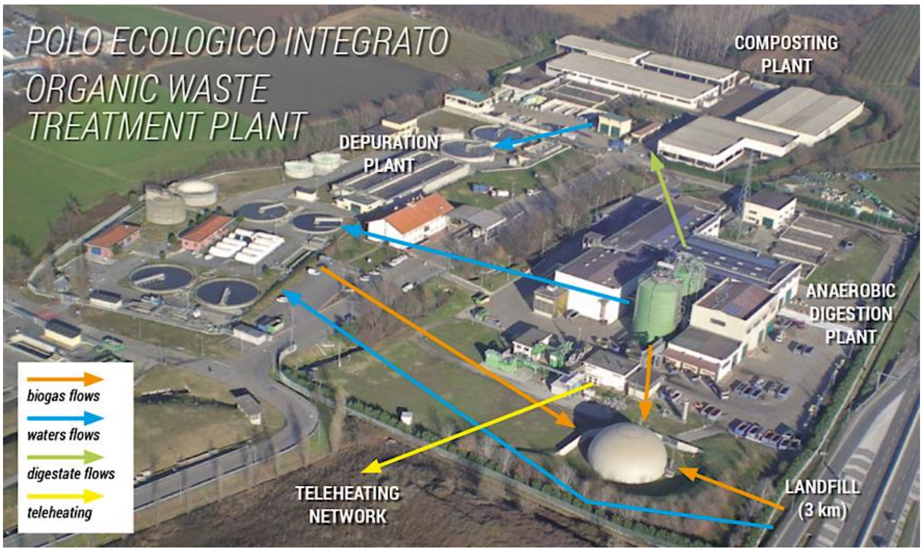

Figure 5-2: Polo Ecologico Integrato – Organic Waste Treatment Plant Representation

Source: image available at ambiente.aceapinerolese.it

5.3 Results and Final Outputs

Biogas

As described before, biogas is a mixture of molecules with methane as the main component, originated from fermentation processes of bio waste. It is considered as a source of renewable energy with zero CO_2 emission, as its amount would balance the carbon cycle started with the organic raw material; and it helps to reduce the amount of methane which would be released with natural processes.

The total amount of biogas produced in 2015 by the Polo was 10.241.500 Nm^3/year; however, its composition and value depend on the percentage of methane.

In the following table is possible to compare standard values of biogas components:

Parameter for Biogas	Measure	From Aerobic Digestion	From Anaerobic Digestion	Natural gas
Lower calorific value	MJ/Nm^3	16	23	40
	kWh/Nm^3	4,4	6,5	11
	MJ/kg	12,3	20	48
Relative density	kg/Nm^3	1,1	0,9	0,63
Upper Wobbe index	MJ/Nm^3	18	27	55
Range of Methane	Vol-%	35-65	60-70	85-92
Heavy hydrocarbons	Vol-%	0	0	9
Hydrogen	Vol-%	0-3	0	-
Range of Carbon dioxide	Vol-%	15-40	30-40	0,2-1,5
Range of Nitrogen	Vol-%	5-40	-	0,3-1,0
Oxygen	Vol-%	1	0	-
Range of Hydrogen sulphide	ppm	0-100	0-4000	1,1-5,9
Ammonia	ppm	5	100	-
Total chlorine as Cl-	mg/Nm^3	20-200	0-5	-

Table 5-2: A comparison of parameters for biogas with different origin

Source: (SGC, 2012)

In 2017 Acea Pinerolese declared that 53% of biogas comes from anaerobic digestion, 10% from the water depuration plant and 37% from the landfill.

To obtain a product with similar characteristics and applications of natural gas, upgrading (refining) processes can be implemented, like water washing, where heavy components are caught by cascading water, and membrane filters. Generally, the loss of methane reaches 2%, allowing to obtain biomethane with at least 96% of methane, mainly used for energy production, fed into pipelines and to power the fleet of vehicles owned by Acea Pinerolese and, theoretically, as car fuel and domestic purposes.

Compost Florawiva

6.000 ton/year of quality compost are produced by the Polo: defined as a concentrate soil improver, it is equivalent to other composts, yet Florawiva has a low environmental impact as it comes from recovering processes. It has been certified for its quality since 2005 by the Consorzio Italiano Compostatori (CIC) and for the production process in respect of ISO 9001 and ISO 14001.

To preserve its quality, the compost composition is regularly checked to meet legal and standard limits. Due to the quality and availability of bio-waste, characteristics can change depending on the season and the percentage of green waste used.

In the table it is possible to find legal limits and a product sample in details. See annex 4 for more details.

Parameters	Legal Limit	Product Sample
pH	6-8.8	6-8.8
Moist (%)	<50	<50
Total Organic Material % p/p s.s.	≥40	≥35
Total Organic Carbon % p/p s.s.	≥20	≥35
Organic Nitrogen % p/p s.s.	>80% N tot	>80% N tot
Humic Carbon %	≥7	≥7
c/n Ratio	≤25	≤25
Cadmium mg/kg s.s.	<1,5	<1
Crome VI mg/kg s.s.	NA	150
Mercury mg/kg s.s.	<1,5	<1
Nichel mg/kg s.s.	<100	<100
Lead mg/kg s.s.	<140	<100
Copper mg/kg s.s.	<230	<150
Zinc mg/kg s.s.	<500	<500
Inherent ≤3.33 mm	Max ≤0,5	Max ≤0,5
Escherichia coli (MPN/g s.s.)	Max 1000	Max 1000
Germination Index %	≥60%	≥60%

Table 5-3: Legal limit and sample for Florawiva compost

Source: (Brussino, 2014)

Energy

In 2015 the Polo produced an equivalent of 46.5 GWh/year of energy and the surplus was sold to external users.

Out of the 17,1 GWh of electric energy produced, 6,7GWh are available to the public and able to satisfy the electricity demand of 2.200 apartments;

Out of the 18,8 GWh of thermal energy produced, 12,5GWh are available to the public through teleheating able to heat 1.600 apartments.

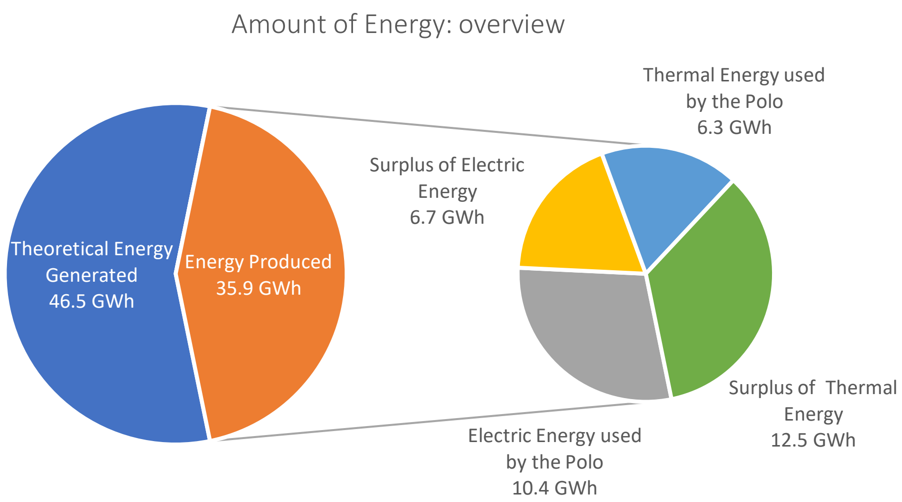

Figure 5-3: An overview of energy produced and consumed by Acea Pinerolese in 2015

Source: (Acea Pinerolese, 2015)

6 CHAPTER SIX

ASSUMPTIONS, METHODOLOGY AND RESULTS

6.0 INTRODUCTION

The aim of this chapter is to analyse the anaerobic digestion process adopted by Acea Pinerolese in order to understand how efficient and effective the process is, by analysing and studying the relationship between input waste and by-products / final products.

In the first section, assumptions taken into consideration are stated.

It follows a detailed description of the process and methodology applied to gather results.

In the third section results are presented and the process output is analysed and compared with input material.

6.1 Assumptions

The analysis is based on 2017 data published by Acea Pinerolese, yet the process, the methodology and the results obtained in this chapter have not been verified by the company; all the following considerations are for explicit academic purpose only.

The following table summarises the flow of material: input and output are highlighted in bold, while the process is described in the next section.

Assumptions:

- Data published by Acea Pinerolese for 2017 present in the annexes are reliable;
- As this research is exclusively focused on bio-waste, other material is not lost or added during the process, including water and sewage which are implicitly considered in anaerobic digestion to calculate the amount of by-products and final products;
- The process is described by macro categories, considering it as a single and continuous process rather than analysing each stage in detail;
- Time is not considered as a variable, as initial input and final output are based over a year period, allowing to assume the process as continuous with no of batch analysis;
- Other assumptions are stated in the following section and described in footnotes.

6.2 DATA AND PROCESS IN DETAIL

In this section data provided by Acea Pinerolese are presented and used to develop the flow of material and the methodology described in the following sections.

The analysis starts with the description of initial material flow that it focuses on biogas and digestate.

6.2.1 INITIAL DATA CONSIDERED:

Anaerobic Digestion Process Data		
Capacity	ton/year ton/week	50.000 900
Type of process	thermophilic; one-stage	
% of solid component	%	10 - 12
Average time	days	14
Digesters Number		2
Digesters Volume	m^3	2.600

Polo Ecologico Average Efficiency		
Biogas production from net waste in the digester	m^3/ton	134
Electricity production	kWh/ton	300
Thermal energy production	kWh/ton	450
Electricity consumed	kWh/ton	75
Thermal energy consumed	kWh/ton	35

Table 6-1: data available for the anaerobic digestion process available at Polo Ecologico Acea Pinerolese
Source: (Acea Pinerolese, 2017)

		Composting	Anaerobic Digestion	Landfill
Total Input	kg	16.394.740	55.533.215	34.117.730
Total Discarded	kg	2.296.040	23.889.184	32.417.080
Net Input	kg	14.098.700	31.644.031	1.700.650
Biogas produced	m^3	3.650.717		2.588.820
Methane	%	35-55%	65,6%	35-55%

Table 6-2: Material data considered to study the process adopted by Polo Ecologico

6.2.2 Process and Methodology

The stream has been defined by analysing data for input and output provided by Acea Pinerolese and available in Annex 1, from which it has been possible to calculate the following formula for waste to AD (anaerobic digestion):

$$Waste\ to\ AD = Total\ Input - MT\ Output$$

Having

$$MT\ Output = Total\ Output - EWC\ 19\ 12\ 12$$

The total amount of waste as initial input is 55.533.215 kg while the total output of anaerobic digestion is 23.889.184 kg.

Breaking this first stage into two, total output is subsequently split in output from mechanical treatments (MT Output) and output of AD: the first one accounts for 16.690.770 kg of waste plus 38.560 kg, which are discarded as defined by the EWC (European Waste Catalogue) code *19 12 12*[4]*;* the second one, accounting to 7.159.854 kg, represents inherent material discarded from the digester, identified with the *19 06 99* EWC code.[5]

Consequently, the total material going in the digester amounts to 38.803.885 kg, equals to 69,9% of IWA (initial waste amount), while the rest is discarded without contribute to generate relevant final products.

Anaerobic digestion takes 30 days and provides two different outputs: biogas and digestate.

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[4] Assumption 1: as they are not identified either as waste originated from pre-treatments or anaerobic treatment but as waste coming from maintenance and not treated, it is possible to not include them in the overall analysis, as they correspond only to 0,16% of the total output.

[5] Assumption 2: with the code 190699 the EWC identifies waste not otherwise specified from anaerobic treatment; because of this reason, it is possible to assume that EWC code identifies inherent material as output of anaerobic digestion, paying specific attention to include it in the Waste to AD figure.

Biogas

The total production of biogas amounts to 6.932.819 m^3, of which 2.588.820 m^3 come from the landfill as Annex 2 shows, while another 10% comes from the water depuration plant[6], while the remaining 52,7% comes from the Polo, mainly produced through anaerobic digestion.[7]

From literature, biogas density[8] is accepted to be 1,1 kg/m^3, and by knowing the total input material, it is possible to calculate the percentage of Waste to AD which then turns into biogas:

$$Waste\ to\ Biogas = \frac{Biogas\ AD * Biogas\ Density}{Waste\ to\ AD}\%$$

$$Waste\ to\ Digestate = 1 - Waste\ to\ Biogas$$

Results are: 7,2% of IWA becomes Biogas, and 62,6% pf IWA becomes digestate.

Following Biogas path, it is possible to notice from Annex 2 that the daily methane content is 62,7% and 62,5% for the two digesters available identified as Digestor A and Digestor B, having an average of 62,6% of CH_4 content: with this figure, it is possible to say that 4,5% of IWA becomes CH_4 while the other 2,7% turns into other volatile components.

As the amount of biogas fed into pipelines and used as a source of fuel for transportation is unknown, we assume that biogas goes through upgrading processes and it is fully used for Combined Heat and Power (CHP). Thanks to three engines each of 1000kWe[9] and with an electrical efficiency declared from the producer of 34,8% and a thermal efficiency at 48,5%[10], biogas is transformed in 13,3 GWh of heat corresponding to 3,5% of IWA, and 14 GWh of electricity corresponding to 2,5% of IWA; left over accounts as flare gas, equal to 3,6% of total biogas production.

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[6] Data used is gathered from the report available at the following link: http://ambiente.aceapinerolese.it/wp-content/uploads/2017/08/BIOGAS-e-BIOGAS.pdf

[7] Assumption 3: Polo Ecologico is able to collect a percentage of biogas also from composting phase, yet the concentration of methane is not declared, and we assume biogas is comparable to biogas from landfill; however, its impact does not significantly affect final results.

[8] From Biogas basic data with reference to EIA (SGC, 2012)

[9] Data available at the following link: https://www.aceapinerolese.it/fornitura-di-catalizzatori-per-lesercizio-di-tre-cogeneratori-cat-3516-da-1-mw-elettrici-matricole-csz00726-4ek02635-e-4ek02633-c-i-g-6951798530/

[10] Data available at the following link: https://www.cgt.it/sites/default/files/coge_-_panoramica_specifiche.pdf

Digestate

Output different from biogas has to go through a drying process to separate material for composting, wastewater, and inherent material. The last one amounts to 7.159.854 kg, corresponding to 12,9% of IWA, is discarded and together with material from pre-treatment, total discarded material accounts for 43% of IWA, which can become RDF (Refuse-derived fuel) or covering material for landfills.

The amount of material for composting and wastewater are not declared by Acea Pinerolese, yet it is possible to calculate them assuming digestate has an average solid material component of 30%, including solid content of waste, inherent material and sewage.[11]

Assuming that the percentage of solid material is correct, it is possible to calculate composting material as follow:

$$Composting\ Material\ \% = \frac{(Waste\ to\ Digestate - Inherent\ Material) * Solid\ \%}{Waste\ to\ Digestate}$$

Accounts for 14,9% of IWA, together with 10,1 million tons of green waste and sewages are going to generate at least 4.634 tons of Florawiva compost.[12]

Remains of digestate are wastewater and sewage: a third of it goes back to the digester and the rest goes through depuration processes:

$$Wastewater\ \% = 1 - Composting\ Material\ \% - \frac{(Waste\ to\ Digestate - Inherent\ Material)}{Waste\ to\ Digestate}\%$$

It overall accounts for 34,9% of IWA.

Overall results of output are presented in the following section.

[11] Input material of AD corresponds to 10-12% of TS, yet the process is continued, and new material enters in the digester continuously. Taking in consideration that a percentage of water is released together with gas emission, it is realistic to assume that 30% is the maximum amount of solid material present in the digestate.

[12] 4.634 ton corresponds to the amount of compost sold by Acea Pinerolese.

6.3 OUTPUT FROM BIO WASTE TREATED IN 2017 BY POLO ECOLOGICO

From the total input of 55.5 thousand tons of waste, it is possible to assume that ideally intermediate products are 6.932.819 m^3 of total biogas and 6.266.880 kg of composting material that, with green waste and sewages creates compost.

The following figure provides a visual representation of the material flows described through a Sankey Diagram, with figures always referring to the percentage of initial input material.

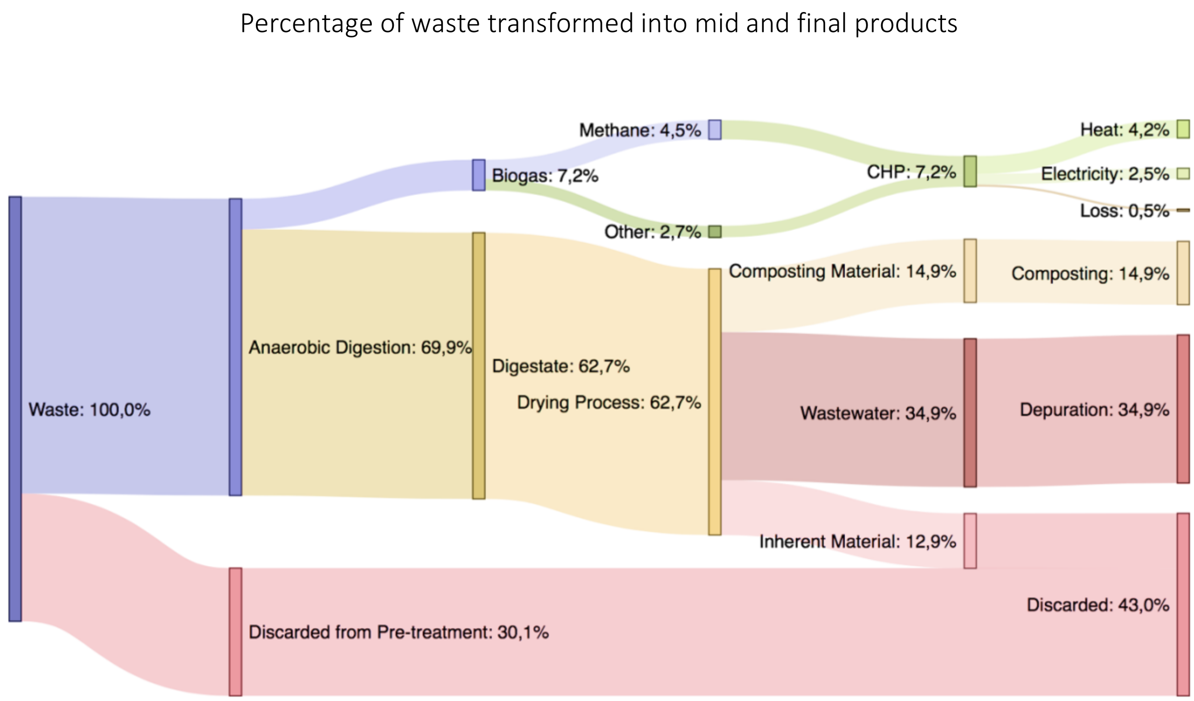

Figure 6-1: Percentage of waste transformed into mid and final products

Source: data available from Acea Pinerolese and Città Metropolitana di Torino

Final outputs as shown in Figure 6-1 consist of:

- Heat: equal to 13,3 GWh and 2.337.189 kg of IWA;
- Electricity: equal to 14 GWh and 1.397.495 kg of IWA;
- Emissions: 0,5% equal to 180.000 m^3 of methane is lost in the process and 281.105 kg of IWA, plus other volatile components;
- Material for Composting: equal to 8.288.473 kg of IWA that, with green waste, will generate 5 thousand tons of quality compost;
- Wastewater and sewage: equal to 19.339.770 kg of IWA going through depuration processes and contributing with biogas generation;
- Discarded Material: equal to 23.889.184 kg of IWA and it can become RDF or covering material for landfills;

The same figures are shown in the following table, illustrating the equivalent in kg for a ton and for the total input material of Acea Pinerolese for 2017.

From	Value	Equivalent for 1.000 kg / a ton	Equivalent to kg of total input	To
Waste	69,9%	699	38.803.885	Anaerobic Digestion
Anaerobic Digestion	7,2%	72	4.015.789	Biogas
Biogas	4,5%	45	2.509.868	Methane
Biogas	2,7%	27	1.505.921	Other
Methane	4,5%	45	2.509.868	CHP
Other	2,7%	27	1.505.921	CHP
CHP	4,2%	42	2.337.189	**Heat**
CHP	2,5%	25	1.397.495	**Electricity**
CHP	0,5%	5	281.105	**Loss**
Anaerobic Digestion	62,7%	627	34.788.096	Digestate
Digestate	62,7%	627	34.788.096	Drying Process
Drying Process	14,9%	149	8.288.473	Composting Material
Drying Process	34,9%	349	19.339.770	Wastewater
Composting Material	14,9%	149	8.288.473	**Composting**
Wastewater	34,9%	349	19.339.770	**Depuration**
Waste	30,1%	301	16.729.330	Discarded from Pre-treatment
Drying Process	12,9%	129	7.159.854	Inherent Material
Discarded from Pre-treatment	30,1%	301	16.729.330	**Discarded**
Inherent Material	12,9%	129	7.159.854	**Discarded**

Table 6-3: Flow of material from input to output in percentage and equivalent to kg of total input

Another output not mentioned before but present in the main phases of the process is gas emission, which is taken into consideration especially for potential losses of CH_4, the concentration of odour and environment protection.

With regard to methane dispersion, around 2% of the total methane content of biogas is lost during the process. To reduce GHG emission and maximise energy production, it is essential to measure and monitor the percentage of methane released while implementing improvements to keep the system as isolate as possible.

On average, the methane dispersion of a plant working with biogas is 1,9% of the total production. This value increases when the system and especially the upgrading machine is overloaded; on the other hand, with off-site gas utilisation, especially in a new plant, methane dispersion can be below one percent and as low as 0,3%. (Fredenslund & Scheutz, 2017)

For Polo Ecologico, main emissions are due to:

- Use of biofilter: due to anaerobic digestion process, air is constantly filtered with a biofilter for each digester to remove traces of oxygen, to store biogas while releasing other gases. Regular checks on off-gas has shown a percentage of methane at an average of 3,5 %v/v per biofilter;
- Upgrading process: to obtain a standard level of CH_4 in biogas, Acea Pinerolese has adopted a washing and membrane filtering process; each of them guarantees a yield above 96% of methane concentration in the final product, but also warns about retention of methane around 1% together with other components meant to be retained;
- Transportation and distribution: as said before, off-site utilisation reduces the risk of methane dispersion, which increases if fed into pipelines and distributed in the network.

The following tables report the emission limits per composting and anaerobic process and technology, all evaluated at full speed in hourly average.

Composting

Two Biofilters		Per biofilter	Limit per Filter
Ammonia	mg/m³	<1,0	5
TOC	mg/m³	13,3 ± 6,8	50
Hydrogen sulphide	mg/m³	<0,2	2
Odour concentration	ou(E)/m³	62	300

Anaerobic digestion

Three Biofilters		Per biofilter	Limit per filter
Ammonia	mg/m^3	<2,0	5
TOC	mg/m^3	26,9 ± 4,3	50
Hydrogen sulphide	mg/m^3	<0,4	2
Odour concentration	$ou(E)/m^3$	86	300

Boiler		Value
TOC	mg/m^3	17,7 ± 9,6
Total Dust	mg/m^3	0,43 ± 0,2
Moisture	% v/v	13,28
CO	mg/m^3	1,98
Nitrogen Oxides	mg/m^3	71,9 ± 11
Oxygen	%	4,56 ± 0,71
Sulphur Oxide	mg/m^3	2,575
CO2	%	9,07 ± 0,43

Three engines		Per engine
TOC (non-metallic)	mg/m^3	14,1
Total Dust	mg/m^3	0,36 ± 0,13
Oxygen	%	8,6
CO	mg/m^3	241,6
Nitrogen Oxides	mg/m^3	306,3
Hydrochloric Acid	mg/m^3	<0,2
Hydrofluoric Acid	mg/m^3	<0,1

Off-gas per digester		Per off-gas
Total Dust	mg/m^3	0,211
CO	mg/m^3	<1,0
Sulphur	mg/m^3	< 2,0
CO_2	% v/v	20
CH_4	% v/v	3,5
O_2	% v/v	<1
Hydrogen sulphide	% v/v	<0,001
TOC	mg/m^3	<1,0

Table 6-4: emission limits per composting and anaerobic process and technology

Source: Autorizzazione AIA 2017 Acea Pinerolese

7 CHAPTER SEVEN

VALUE CREATION AND OPPORTUNITIES

7.0 INTRODUCTION

In this chapter, the value of by-products and final products is estimated through assumptions and compared to evaluate the added value gained from the process.

Furthermore, the amount of biogas declared by Acea Pinerolese is analytically checked while the amount of compost is estimated.

In the last section, additional future value creation from projects under development is investigated.

All assumptions are declared and justified in the text or in the footnotes.

7.1 BIOGAS

Biogas is not directly sold by Acea Pinerolese to third parties, but it is used for cogeneration, fed into pipelines, or as traction fuel after upgrading processes. It is collected from the Polo Ecologico and the landfill with the following characteristics:

Origin of Biogas	m^3	CH_4 content in %	CH_4 content in m^3
Polo Ecologico	4.343.999	62,6%	2.719.343
Landfill	2.588.820	40,0%	1.035.528
Total	6.932.819	54,2%	3.754.871

Table 7-1: Characteristics of biogas collected by Acea Pinerolese

Source: data available in Annex 2

Before assessing the possible economic value of biogas, it is possible to check the amount of biogas provided by Acea Pinerolese from the Polo and from the landfill.

7.1.1 COMPARING BIOGAS PRODUCED BY POLO ECOLOGICO WITH ACEA PINEROLESE DATA AND LITERATURE

- Data provided by Acea Pinerolese:

$$Amount\ of\ Biogas = Amount\ of\ waste\ going\ to\ the\ digesters * Biogas\ yield$$

As it is possible to see from Annex 1, the net amount of waste going in the digester is equal to 31.664.031 kg.

Biogas yield provided by Acea Pinerolese in Table 6-1 is 134 m^3 per ton of waste going into the digester.

Data provides a result of 4.240.300 m^3 of biogas, with a deviation of 2,39% from the value provided by Acea Pinerolese in 2015. Thus, it is possible to calculate the real biogas yield obtained for 2017 as:

$$Biogas\ yield = \frac{Amount\ of\ waste\ going\ to\ thedigesters}{Amount\ of\ Biogas}$$

Obtaining a Biogas yield of 137,28 m^3 per ton of waste going through anaerobic digestion.

- Analytical methods provided by literature:

ENEA, an Italian R&D agency, has analysed the biogas potential from the OFMSW[13], assuming the following figure of biogas yield as correct, it is possible to check biogas amount. (F. Reale, 2009)

$$Biogas\ Yield = 0.78\ \frac{Nm^3}{kg\ TVS}$$

The figure is in normal cubic meter over kg of TVS: TVS stands for total volatile solid, representing the 90% of TS (total solid), which corresponds to 18% of OFMSW. (F. Reale, 2009)

$$Biogas\ Yield = 0.78\ \frac{Nm^3}{kg\ TVS} \sim 0.140\ \frac{Nm^3}{kg} = 140\frac{Nm^3}{ton}$$

With the net amount of waste going into the digester equals to 31.664.031 kg, it is possible to estimate the value of biogas produced by the Polo Ecologico through the following formula:

$$Amount\ of\ Biogas = Amount\ of\ waste\ going\ to\ the\ digesters * Biogas\ yield$$

Having as result a figure of 4.442.822 m^3 of biogas, with a deviation of 2,33% from the figure provided by Acea Pinerolese in 2017.

[13] Organic Fraction of Municipal Solid Waste

7.1.2 BIOGAS FROM LANDFILL

Concerning biogas from landfill, the amount of waste threated by Acea Pinerolese is not known and it would not be relevant for this analysis as the amount of waste is not constant over time. Landfills have a life cycle with a minimum 30-year lifetime characterized by five main phases, during which the production of biogas is not a constant as the following graph shows.

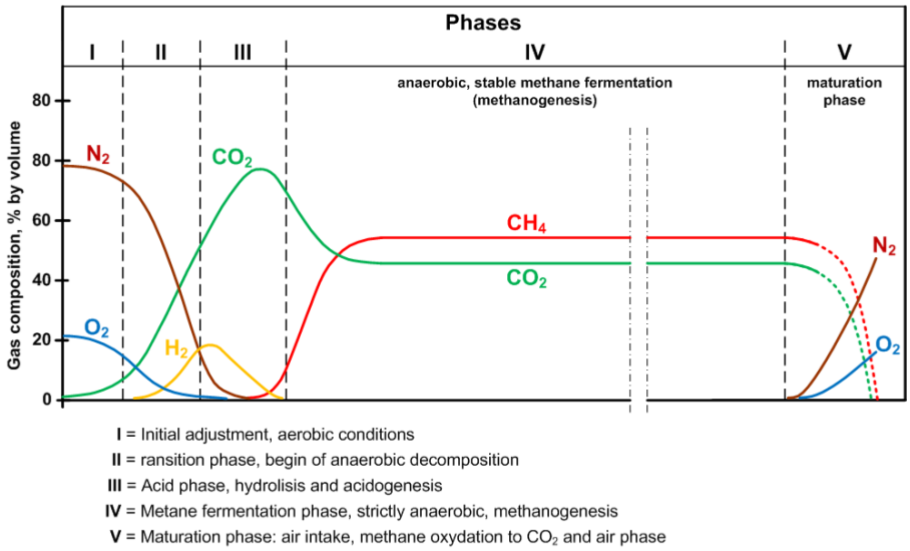

Figure 7-1: gas production during the life cycle of a landfill

Source: image available at (Gandiglio, 2015)

Generally, the amount of biogas produced by landfilled waste is not in relation with the quantity of MSW stocked as it changes over time, although it is possible to find figures in literature. From literature purpose only, biogas yield from landfill can be assumed at 43,1 m^3 / ton of MSW and we assume correct the amount of biogas declared by Acea Pinerolese. (Gandiglio, 2015)

7.2 Result

Having a difference of less than 2,5% and similar value of biogas yield regarding biogas from the Polo Ecologico, it is possible to state that the amount of biogas provided by Acea Pinerolese produced and the landfill is consistent with figures from literature and relevant for the following evaluations.

It is now possible to estimate the potential economic value for biogas as follow:

7.2.1 Value of biogas

To evaluate biogas methane is taken into consideration as its most valuable component.

An economic value of methane considered as raw material, with a percentage of CH_4 above 96%, is at 31,08 € cent per Sm^3.[14] Taking into consideration the different amount of CH_4 in biogas as suggested in Table 7-1, the corresponding economic value attributed to biogas is as follows:

Parameter	Value
Total methane	3.754.871 m^3
Value per Sm^3	31,08 € cent
Total Value per Sm^3	1.167.014 €
Biogas yield	137 Nm^3 per ton of OFMSW
Final value	**€43 per ton of OFMSW**

Table 7-2: value of biogas per ton of OFMSW

[14] The price of methane is provided by ARERA as the average value of raw material sold to an average domestic user for the first three quarters of 2018. More details on www.arera.it

7.2.2 VALUE OF BIOGAS TRANSFORMED IN ELECTRICITY AND HEATING

As described in Chapter 6.3, Acea Pinerolese gains value of biogas through cogeneration by producing and selling electricity and heating.

Assuming all the biogas produced is transformed in energy and upgrading processes are not essential for this purpose, it is possible to evaluate the economic value from the total amount shown in Annex 3.

Acea Pinerolese declares to produce a total of 27,3 GWh from cogeneration, 13,3 GWh as electricity and 14 GWh as thermal energy: the total potential economic value is calculated with an average market price for final consumer:

- For electricity, data are provided by ARERA, as the Italian regulatory authority for the energy networks and the environment, which has calculated a total tax-free price of 17,32 € cent per kWh for a total potential value of €2.303.720[15];
- For teleheating, it has been chosen Iren as the main Italian operator in the sector and operating in Turin, which has provided a tax-free market price for teleheating at 8,03 € cent per kWh for a total potential value of €1.124.159[16];

This value can increase taking national incentives in consideration; in detail, considering incentives presented with the D.M. 06/07/2012[17] and comparing it with the previous model based on green certificates for new, adapted or converted plant similar in size and installed power and capacity, it is possible to gather the following figures:

- ARERA provides a cost per one kWh of electricity at 9,059 € cent;
- The basic incentive for a plant producing biogas from biological origin by-products with an installed power between 1000 and 5000 kW is at 125 €/MWh;
- The incentive for cogeneration and more specifically for teleheating is at 40 €/MWh.

[15] ARERA provides the price of electricity in kWh as the average value of electricity sold to an average domestic user for the first three quarters of 2018. More details on www.arera.it

[16] Iren provides the price of heating through teleheating in kWh for domestic building in Turin which consumes up to 350.000 Mcal/year for the first three quarters of 2018. More details on www.irenlucegas.it

[17] Data gathered and adapted from the Art. 8 “Disposizioni specifiche per gli impianti alimentati da biomassa, biogas, e bioliquidi sostenibili” from the D.M. 06/07/2012 available at www.sviluppoeconomico.gov.it

Accepting that 1 m^3 of biogas corresponds to 1,8-2 kWh of electric power and waste disposal cost is at € 90 per ton, it is possible to calculate the amount of incentives for a ton of OFMSW as follow:

Parameter	Value
Potential electric power	1 m^3 of biogas ~ 1,8 kWh
Biogas yield	137 Nm^3 per ton of OFMSW
Value of 1 kWh for producer	9,059 € cent per kWh
Value for a ton of OFMWS	24,82 €/ton per kWh
Base Incentive	0,125€ per kWh
Teleheating Incentive	0,04 € per kWh
Final value	**63,03 €/ton per kWh**

Table 7-3: Value of biogas transformed in Electricity and Heating

7.2.3 VALUE OF BIOGAS TRANSFORMED IN BIOMETHANE FOR VEHICLE TRACTION

The use of methane as a traction fuel has been available for private purposes since the beginning of 2000, having the Asia-Pacific region as the driving force of this market. Italy has invested in the potential of natural gas, becoming the main European operator advantaged by a widespread distribution network and FIAT as the main developer of natural gas engines for private and commercial vehicles.

Nowadays Italy is sponsoring the use of biomethane for transportation through incentives as reported in the D.M. MiSE 02/03/2018, which becomes very useful for this analysis. In fact, since 2014 Acea Pinerolese has participated in two projects in collaboration with FCA, Hysytech, and Politecnico di Torino to research the potential of methane and hydrogen obtained from biogas derived from OFMSW, obtaining the permit to test biomethane in its commercial vehicles in 2016.[18]

As a consequence of these evaluations, it is possible to assume that Acea Pinerolese has developed the technology and know-how to produce commercial biomethane for traction purpose, allowing us to evaluate the potential economic value of biomethane for vehicle traction.

[18] Authorisations granted with the protocol 38161 / 2014 and 17918 / 2016 issued by Provincia di Torino

To do so, the plant taken into consideration is comparable with Polo Ecologico, with incentives related to *Biometano avanzato*, roughly described as the result of a process not aimed at the exclusive production of methane from a specific list of input material, including OFMSW, amounting to:

- Incentive for Biometano avanzato at 375 €/CIC, having one CIC (Certificati di Immissione in Consumo) equals to 10 Gcal of biofuel released for consumption;
- A possible extra 20% if methane is liquefied and/or distributed, value not considered by Acea Pinerolese.

The possible economic value of biomethane for vehicle traction purpose is estimated taking the following assumption in consideration:

- The volume and density of processed biogas through upgrading processes is equal to the density and volume of total methane produced by Acea Pinerolese;
- Upgrading cost accounts as operational cost;
- Referring to the value in Table 5-2 for natural gas.

Parameter	Value
Relative density of natural gas	0,63 kg/Nm^3
Biogas yield	137 Nm^3 per ton of OFMSW
Calorific Value	11,945 Gcal/ton
CIC	1 CIC for every 10 Gcal
Value per CIC	€375
Corresponding value of CIC per a ton of OFMSW	€ 38,66
Value of natural gas per Sm^3	31,08 € cent
Final value	**~ € 81 per ton of OFMSW**

Table 7-4: Value of biogas transformed in Biomethane for vehicle traction

7.3 DIGESTATE AND RESULTS

Digestate is not directly sold by Acea Pinerolese to third parties, but it is used to create compost through a composting process, obtaining a more valuable product.

To evaluate the theoretical economic value of digestate, the amount of composting material taken into consideration is equal to the net input of OFMSW and green waste as shown by Annex 1, which includes a part of solid and liquid material from anaerobic digestion plus the green waste, sewages and water.

Parameter	Value
Solid Input	15.475.380 kg
Sewage Input	919.360 kg
Discarded Material	2.296.040 kg
Net Input	14.098.700 kg

Table 7-5: detail of material for composting in kg

Source: Annex 2

7.3.1 VALUE OF DIGESTATE

To evaluate the possible economic value of digestate, commercial prices have been taken in consideration.

Wrap.org.uk provides a figure based on the price of typical nutrient content of fertiliser contained in food-based digestate at £4,11 digestate per m^3 and £123,30 digestate applied to 30 m^3/ha. (WRAP, 2012)

Parameter	Value
Conversion rate	£ 1 = € 1,117
Cost per m^3	€ 4,59
Digestate density	1,410 kg/l
Cost per kg	0,3256 € cent
Final value per ton	**€3,26**

Table 7-6: value of digestate per ton

7.3.2 Value of Florawiva compost

Acea does not declare the total amount of compost produced, it only indicates the ton sold. From a report published by the European Commission, it is possible to calculate that 39,22% of OFMSW become compost.

To evaluate the theoretical amount of compost produced by Acea Pinerolese, the amount of composting material taken in consideration is equal to the net input of OFMSW and green waste as shown by Annex 1.

The price corresponds to the average commercial value.

Parameter	Value
Net Input	14.098.700 kg
Percentage of OFMSW becoming compost	39,22%
Theoretical compost amount produced	5.529.871 kg
Florawiva compost sold by Acea Pinerolese	4.634 ton ~ 84% of theoretical amount
Price per ton	**€ 23**

Table 7-7: value of Florawiva compost

7.4 PROJECTS UNDER DEVELOPMENT

- MAT4TREAT Project in collaboration with the Università di Torino: the aim is to reduce organic micropollutants from waste water using compost matrix as molecular filter;

- BIOROBURPLUS Project in collaboration with Politecnico di Torino: the aim is to extract hydrogen from biogas and use it for fuel purpose with a cost-effective constraint;

- LIFECAB Project in collaboration with the Università di Torino: the aim is to study a new bio anaerobic process to enhance performance, reduce the environmental impact and increase the economic return;

- PROGEO Project in collaboration with PROGEO: the aim is to improve the profitability of small thermoelectric power generation by converting CO_2 generated from anaerobic digestion in biomethane to reduce the environmental impact and increase the energy value.

All the projects mentioned will further help in closing the loop in a Circular Economy perspective, by improving the impact on the environment with a reduction of solid pollutant and volatile emissions. At the same time, these and future projects will add an extra value to waste especially by implementing results on an economy of scale, furthering support the potential economic value of transformed waste.

8 CHAPTER EIGHT

VALUE PER FINAL PRODUCTS

8.0 INTRODUCTION

This chapter continues with the analysis of potential economic value from Chapter Seven, adding a financial analysis of Acea Pinerolese for 2017.

In the first section results are compared and analysed.

In the third section, three potential scenarios are presented aiming to define different profit sources.

In the last section, a financial analysis of the company is presented to highlight the real performance of Ace Pinerolese for 2017.

8.1 Comparing Results

In this section results obtained from biogas and digester are compared with the potential value of final products.

A more detailed comparison would have involved the cost related to the overall process to obtain different final products and the disposal cost avoided.[19]

The value added from the transformation of biogas into different products based on methane is as follow:

- From cogeneration purpose the added value corresponds to an increment of 65% from the initial value of biogas;
- From biomethane the added value corresponds to an increment of 76% from the initial value of biogas.

For a ton of OFMSW	Value	Incentive impact	Without Incentive
Value of biogas	€ 43 per ton	-	€ 43 per ton
Value of cogeneration	€ 63 per ton	65%	€ 22,34 per ton
Value of biomethane	€ 81 per ton	48%	€ 38,66 per ton

Table 8-1: comparison of potential value of biogas

An extra value added from material going through composting process is as follows:

For a ton of product	Value
Value of digestate	€ 3,26 per ton of digestate
Value of digestate as final compost[20]	€ 7,60 per ton of compost
Value of compost	€ 23 per ton of compost
The added value is equal to	+167% of biogas value

Table 8-2: comparison of potential value of compost

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[19] It has not been possible to conduct the mentioned comparison as it is not known the process cost per single and or overall process. Disposal cost per a ton of OFMWS is quantified as 90€.
[20] Assuming that the amount of Florawiva compost sold is equal to total production, it follows that a kg of final product requires 3,40 kg of digestate.

8.2 DEFINING POSSIBLE SOURCES OF PROFIT

Taking in consideration the value from Table 8-2, it is possible to define three scenarios through a simple Linear Programming implementation. The problem has been set in the Solver of Excel as follow:

Variables:

n: type of valorisation;

X_n: ton per type of valorisation;

I_n: incentive for a ton of *n;*

M_n: maximum total incentive per *n*;

C_n: Price per ton per *n.*

Set Objective:

Maximise the final profit while maximising the profit from incentive per type of valorisation:

Objective: Max (P)

With $P = \sum n (X_n * (I_n + C_n))$

Constraints:

$\sum X_n = A$, with A as the total amount of OFMSW treated set at 31.644 ton;

$X_n * I_n \leq M_n$, Incentive constrait;

Domain:

$X_n \in Z_+$, with $n \in N$ (c=cogeneration, b=biomethane)

Results:

Case Number	Ton per cogeneration	Ton per biomethane	Profit
Case 1: no limit for M_n	-	31.664	€ 2.570.795 Opportunity cost: (€706.912) Net Profit: €1.863.884
Case 2: $M_c = M_b =$ €1M $X_c \geq 35\%$ of $\sum X_n$	11.075	20.569	€2.369.083 Incentive: €1.245.861
Case 3: as Case 2 with $X_b \leq 35\%$ of $\sum X_n$	20.569	11.075	€2.196.188 Incentive: €1.265.108

Comment:

- Case 1 describes a scenario with no incentive constraints: as the whole production would be shifted to biomethane, the cost related to not production of cogeneration is deducted from the potential profit;
- Case 2 imposes two limits: to avoid the opportunity cost the production, at least 35% of input material has to be valued as cogeneration and incentives are equal to €1M per each n;
- Case 3 takes in consideration a realistic scenario: considering the risk to enter in the new biomethane market for traction, the amount of total biomethane is limited to 35% of input material.

8.3 Financial Analysis

From the income statement in Annex 5, it is possible to highlight the following main figures and analyse their impact on the amount of waste treated by Acea Pinerolese.

8.3.1 Financial Data

Main Figure	31/12/2017
Revenue	€51.494.484
Added Value	€28.519.624
Final EBIT	€4.789.995
Net Profit	**€3.235.672**
Profit margin	**6,28%**

Table 8-3: Main figure of income statement, 2017

Acea Pinerolese stated an initial investment of €16,6M. (Acea Pinerolese, 2015)

For a similar plant, it is possible to suppose the following figures per year:

- An initial investment rounded up to €20M financed with s a loan with a fix interest at 5%;
- A net profit equals to €3M per year;

→ The payback time is of exactly 8 years.

Calculating the net profit per ton of waste, it is then possible to compare the real value gained by Acea Pinerolese per ton of waste with the potential value analytically estimated in Chapter Seven.

The waste treated by Acea Pinerolese in 2017 is shown in the following table.

Waste Treated	Ton
Waste Collected by Acea Pinerolese	68.142
Unsorted	31.141
Sorted	37.001
of which OFMSW	10.320
OFMSW imported	45.213
Total Waste Treated	**113.355**
of which OFMSW	55.533

Table 8-4: total waste treated by Acea Pinerolese, 2017

Impact of Acea Pinerolese revenue on total waste treated:

- Revenue per ton of Total waste Treated: €486;
- Net Profit per ton of Total Waste Treated: € 31
  - Value added per kg of Total Waste treated: € 0,27;
  - Total Cost per kg of Total Waste treated: € 0,22.

Impact of Acea Pinerolese revenue on OFMSW treated:

- Revenue per ton of OFMSW: €927;
- Net Profit per ton of OFMSW: € 58
  - Value added per kg of OFMSW: € 0,51;
  - Total Cost per kg of OFMSW: € 0,41.

Comparing estimated data from an analytical analysis with data from the income statement

As stated before, biogas is assumed to be fully used for cogeneration purpose only; in sight of this, it is possible to make the following consideration:

The net profit of € 58,27 per ton of OFMSW obtained from the income statement is close enough to the one estimated analytically in Chapter 0 of € 63,03 for cogeneration, with a variation of 8%. This variation could be due to round up on the estimation process, one or more incorrect assumptions, tax impact or costs not considered.

However, a variation of 8% can be considered correct to estimate its potential economic value.

8.3.2 COMMENT ON FINANCIAL ANALYSIS

Economic indicators are information gathered from a balance sheet or income statement of a company used to evaluate its performances in the market and in contrast with previous years of activity.

The main indicators to evaluate the performance of a company are:

- ROE: net income / equity, it measures the profitability of a company to evaluate the return generated from investments;
- ROI: net income / investment, it measures the efficiency of an investment;
- ROS: operating income / revenue, it measures the net profit as a percentage of revenue;
- EBITDA/Income: a value of this ratio >18% is considered at a good level of revenues to evaluate the profitability on sales in terms of economic return and own capital at the same time;
- Financial Costs / Income: 5% is taken as the acceptable limit to evaluate the cost of financial debt on turnover;
- Equity Ratio: a value of this ratio >30% is considered at an excellent level of capital strength in terms of ratio between equity and total assets of the balance sheet;
- Acid test: it is the liquid assets / current liabilities ratio excluding warehouse stock, allowing to understand the payback ability of a company.

Economic Indicators	31/12/2017	% of Var.	31/12/2016
ROE	5,2%	-0,62% ↓	5,8%
ROI	2,5%	-0,51% ↓	3,0%
ROS	10,2%	-2,21% ↓	12,4%
EBITDA / Income	20,9%	-2,73% ↓	23,6%
Financial Costs / Income	3,0%	-1,54% ↓	4,6%
Equity Ratio	44,9%	+2,90% ↑	42,0%
Acid Test	56,8%	-8,91% ↓	65,7%

Table 8-5: Economic indicators for 2017 and 2016

ROE, ROI, and ROS have been subjected to a negative variation due to a reduction in profit and a slight increase of cost. For 2017, income tax has reduced of -36,4% respect 2016, and overall the profit margin has decreased of 5,34% in respect of the previous year.

Acid test shows the average position of the company in its sector, and it is subject to a variation of interest rate for medium and long-term funding.

On an overall analysis, there is not remarkable risk of financial and non-financial nature for Acea Pinerolese, showing consistent results and comparable with previous ones.

9 FINAL CONSIDERATION

From a general analysis, this study has tried to gather data and information from reliable sources by checking the truthfulness of them when possible.

As findings have been already discussed in previous chapters, this last part aims to evaluate the overall performance of Acea Pinerolese from an economic and technological perspective.

Acea Pinerolese has been able to turn the disposal cost of waste, estimated at €90 per ton of OFMSW, into an economic value calculates at €58 per ton of OFMSW, able to develop research and development, able to create a benchmark in the valorisation of OFMSW, and able to reduce the overall impact on the environment of 76.000 tons of CO_{2equ}.

Through further R&D investment, Acea Pinerolese will be able to add an addition value per ton of waste treated, increasing the circularity of the company and the position in its market.

One more last analysis can be conducted with regard to the opportunity cost of OFMSW

Assumptions:

- The net amount of OFMSW is equal to 70% of OFMSW;
- Data for 2016 published by ISPRA are correct and similar to data for 2017;
- The following information obtain from this study are as follows:

For a ton of OFMSW	Value
Biogas Yield	137 Nm^3 per ton of Net OFMSW
Value of cogeneration	€ 63 per ton
Value of biomethane	€ 81 per ton
Compost Yield	39,22% of Net OFMSW
Value of compost	€ 23 per ton of compost

The total opportunity cost for the organic fraction of municipal solid waste for the Metropolitan City of Turin, Piedmont, and Italy are as follows:

	Value of Cogeneration	Value of Biomethane	Plus the value of Compost
Turin	€ 8.356.016	€ 10.743.449	€ 1.196.449
Piedmont	€ 17.983.595	€ 23.121.765	€ 2.574.965
Italy	€ 287.394.328	€ 369.506.993	€ 41.150.306

Table 9-1: Opportunity cost per Turin, Piedmont, Italy

Source: total waste amount data gathered from ISPRA

10 CONCLUSION

In this study, the benefits granted from the implementation of a Circular Economy approach have been investigated and presented by analyzing the organic fraction of municipal solid waste treated by Acea Pinerolese.

Through the study of processes and material flows, it has been possible to quantify the amount of organic waste transformed into new resources and the corresponding potential economic value.

The finding presented have been discussed in order to extend their application on comprehensive analyses, allowing us to prove objective benefits from a Circular Economy implementation.

In detail this approach is able to:

- Fulfil the provisions and objectives sponsored by the implementation of a Circular Economy approach;
- Generate awareness to spread circular, sustainable, and eco-compatible approaches concerning waste disposal practices;
- Reduce the impact of GHG emission due to a circular process;
- Optimise the use of resources while generating greater profits;
- Promote the use of renewable resources;
- Generate new opportunity with job creation supported by public funds.

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Annex 1

	RELAZIONE		M.05.IA_REL
acea	N° Progetto IA-PEI-100-ND-RG-003		Rev. 0 del 06/09/2010
L'innovazione è il nostro territorio	RA-…………… Ord. ……………	CC …………… CO ……………	Pag. 3 di 19

ALLEGATO 1

Quantità e tipologia dei rifiuti trattati e prodotti dalla linea secco, linea umido digestione anaerobica e linea umido compostaggio:
Si allegano le tabelle recanti le informazioni richieste.

RIEPILOGO RIFIUTI TRATTATI DETTAGLIATO PER CODICE C.E.R	totale			
	linea umido compo	linea umido dig. An.	linea secco	tot
020103	0	24.380	0	24.380
020106	0	0	0	0
020201	0	0	0	0
020203	0	7.370	0	7.370
020204	0	0	0	0
020304	0	510.820	0	510.820
020501	0	72.620	0	72.620
020502	43.160	810.140	0	853.300
020601	0	960.478	0	960.478
020703	0	0	0	0
020704	0	0	0	0
020705	757.900	0	0	757.900
030101	0	0	0	0
040222	0	22	0	22
070299	0	0	0	0
150101	0	0	0	0
150102	0	0	1.700	1.700
150106	0	0	335.020	335.020
161002	0	283.660	0	283.660
170604	0	0	0	0
170904	0	0	0	0
190501	0	0	0	0
190604	0	0	0	0
190699	6.266.880	0	0	6.266.880
190801	0	25	0	25
190805	118.300	170.400	0	288.700
190809	0	0	0	0
191207	0	0	0	0
191212	0	17.520	779.140	796.660
200108	0	51.801.610	0	51.801.610
200138	0	0	0	0
200201	9.208.500	0	0	9.208.500
200301	0	0	31.111.510	31.111.510
200302	0	872.370	0	872.370
200304	0	0	0	0
200306	0	1.800	0	1.800
200307	0	0	1.890.360	1.890.360
TOTALE SCARTI PRODOTTI	16.394.740	55.533.215	34.117.730	106.045.685

RIEPILOGO SCARTI PRODOTTI DETTAGLIATO PER CODICE C.E.R	totale			
	linea umido compo	linea umido dig. An.	linea secco	tot
190699	0	7.159.854	0	7.159.854
191203	0	0	828.160	828.160
191207	352.160	0	0	352.160
191207	0	0	0	0
191210	0	0	9.107.420	9.107.420
190503	95.980	0	0	95.980
191212	1.254.940	0	0	1.254.940
190699	0	0	0	0
200201	74.740	0	0	74.740
150104	0	0	0	0
191212	0	0	0	0
191212	0	280.560	0	280.560
191212	0	0	0	0
191212	0	0	0	0
191212	0	0	1.887.400	1.887.400
191212	0	0	0	0
191212	0	0	0	0
191212	0	0	0	0
191212	0	779.100	0	779.100
191212	0	0	9.993.800	9.993.800
191212	0	1.760.840	0	1.760.840
191212	0	2.740.260	0	2.740.260
191212	0	11.130.010	0	11.130.010
191212	0	0	0	0
190604	0	0	0	0
200108	0	0	0	0
vari da manutenzione e rifiuti non trattati	518.220	38.560	10.600.300	11.157.080
	2.296.040	23.889.184	32.417.080	58.602.304

Catalogo Europeo dei Rifiuti (CER) = European Waste Catalogue (EWC)

ANNEX 2

	RELAZIONE N° Progetto IA-PEI-100-ND-RG-003		M.05.IA_REL Rev. 0 del 06/09/2010
acea PINEROLESE L'INNOVAZIONE È IL NOSTRO TERRITORIO	RA-……………. Ord. ……………	CC ……………. CO …………….	Pag. 9 di 19

ALLEGATO 7

Le analisi relative al biogas prodotto vengono determinate attraverso un impiantistica fissa che verifica in linea i valori di metano, anidride carbonica presenti nel biogas. Il P.C.I. sul t.q. viene determinato analiticamente

Tabella 2. Dati annuali biogas (le letture di portata si riferiscono ai misuratori oggetto di verifica da parte dell'agenzia delle dogane).

Anno 2017		
media giorno % metano		
Media %/gg metano linea A	62,7	%
Media %/gg metano linea B	62,5	%

Volumi di biogas prodotto		
Totale Biogas da polo ecologico e depurazione	4.343.999	m3
Totale Biogas da impianto discarica "Torrione"	2.588.820	m3
Sommatoria Biogas prodotto	6.932.819	m3

Volumi di biogas utilizzati		
Totale Biogas a linea Cogeneratori	6.688.560	m3
Totale Biogas a Torcia	244.259	m3

PCI sul t.q.		
Da polo ecologico e depurazione	27.062.885	KWhT
Linea Cogeneratori	33.054.550	KWhT

Si allegano i rapporti di prova n°rp2017_17sp1391-026/027/028/029 del 24/05/2017 e n°17sa20611/12/13/14 del 04/01/2018 relativo alla qualità biogas del polo ecologico e della discarica torrione dove è contenuto anche il parametro H_2S.

	RELAZIONE N° Progetto IA-PEI-100-ND-RG-003		M.05.IA_REL Rev. 0 del 06/09/2010
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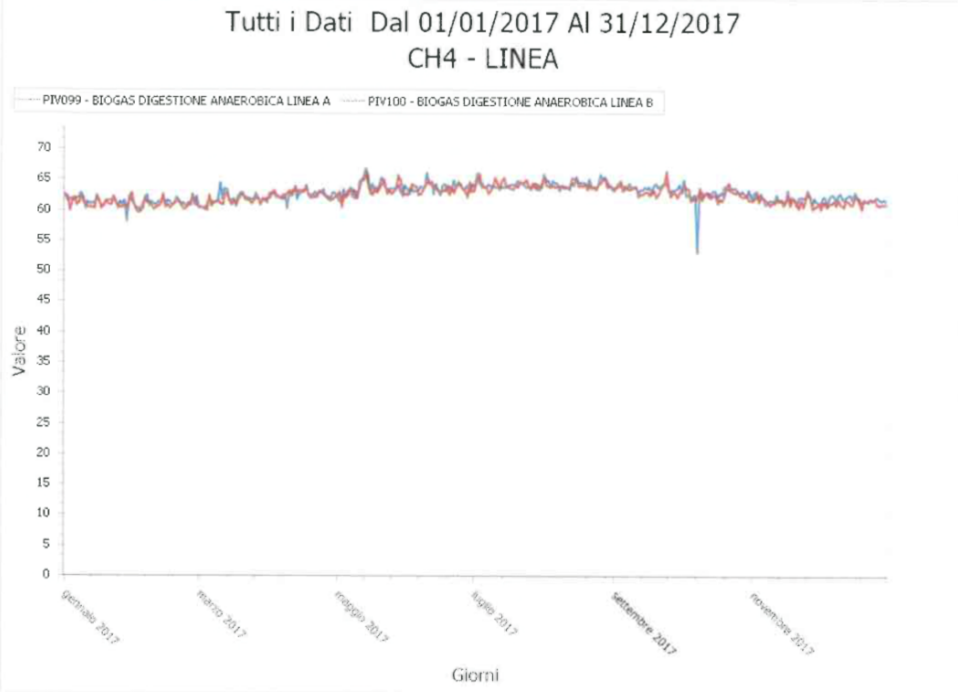
Figura 1 Concentrazione metano linee A e B biodigestione



	RELAZIONE N° Progetto IA-PEI-100-ND-RG-003		M.05.IA_REL Rev. 0 del 06/09/2010
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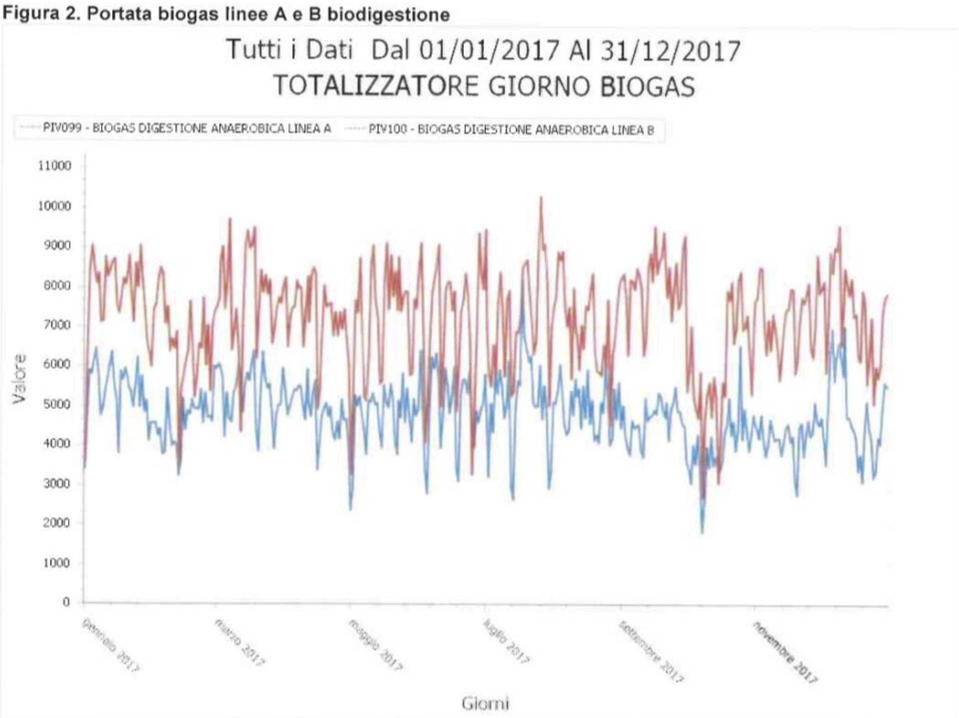
Figura 2. Portata biogas linee A e B biodigestione



ANNEX 3

Azioni Correlate – articolo 2350 Codice Civile

Ai sensi di quanto previsto all'articolo 5 del vigente Statuto di seguito riportiamo un prospetto riepilogativo di conto economico di settore redatto secondo i criteri dettagliatamente riportati all'articolo 12 dello stesso Statuto.

Il conto economico del settore idrico integrato è così riepilogabile:

Conto economico - Servizio Idrico Integrato	**Euro**
A) Valore della produzione	25.350.096
B) Costi della produzione ed oneri/proventi finanziari	19.936.389
A - B) Differenza	**5.413.707**

AREA AMBIENTE

IMPIANTI

- **Discarica**

Nel 2017 la discarica ha smaltito i seguenti quantitativi di rifiuti:

	TOTALE
CER E DESCRIZIONE	**KG**
200301-200303-200307 RIFIUTI URBANI INDIFFERENZIATI	49.150
VARI RIFIUTI SPECIALI NON PERICOLOSI	17.852.320
TOTALE	***17.901.470***

Il quantitativo di biogas complessivamente avviato a recupero energetico nel corso del 2017 ammonta a: mc. 3.658.330

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- **Linea Umido-Digestione Anaerobica e Linea Secco del Polo Ecologico**

Nel 2017 l'impianto ha trattato i seguenti quantitativi di rifiuti

CER E DESCRIZIONE	**KG**
200108 UMIDO	51.801.610
200302 RIFIUTI MERCATALI	872.370
200301 RIFIUTI URBANI NON DIFFERENZIATI	31.111.510
200307 RIFIUTI INGOMBRANTI	1.890.360
ALTRI RIFIUTI	3.975.095
TOTALE	**89.650.945**

- **Linea Umido-Compostaggio del Polo Ecologico**

Nel 2017 l'impianto ha trattato i seguenti quantitativi di rifiuti

CER E DESCRIZIONE	**KG**
200201 VERDE	9.208.520
190805 FANGHI DA DEPURATORE	118.300
190699 FANGHI DA VALORIZZATORE	6.266.880
ALTRI RIFIUTI	801.060
TOTALE	**16.394.760**

Nel corso del 2017 sono state vendute 4.634 Ton. di compost.

- **Impianto di recupero energetico del biogas presso l'Impianto di Valorizzazione**

Nel corso del 2017 sono confluiti all'impianto di recupero energetico del biogas le seguenti quantità:

- dalla discarica: mc 2.588.820
- dal depuratore acque reflue Acea e digestori Valorizzatore : mc. 4.343.999

L'impianto ha prodotto le seguenti quantità di energia:

- energia elettrica prodotta: GWh 13,3 di cui
  - energia elettrica autoconsumata: GWh 8,7 (intero polo)
  - energia elettrica ceduta alla rete:GWh 4,6
- energia termica : GWh 14 (dai soli motori GWh 3,7) di cui 6,5 ceduta al teleriscaldamento e 7,5 utilizzata da Acea.

RACCOLTA RIFIUTI

Nell'anno sono state raccolte complessivamente, nel bacino 12, le seguenti quantità e frazioni:

La percentuale di raccolta differenziata provvisoria ed in corso di validazione ammonta a 54,3 %

C.E.R	RU 2017	TON
	DESCRIZIONE	
200301	Rifiuti Urbani Indifferenziati-discarica	8,08
200303	Rifiuti da pulizia strade-discarica	24,73
200306	Rifiuti da pulizia fognature-discarica	16,34
200301	Rifiuti Urbani Indifferenziati-trattamento	31.031,60
200108	rifiuti biodegradabili da cucine e mense	5.711,94
200302	rifiuti dei mercati	98,77
200201	rifiuti biodegradabili	4.505,96
200201	rifiuti biodegradabili-ASS	3,37
150101	imballaggi in carta e cartone	1.479,69
150101	imballaggi in carta e cartone-ASS	1.585,80
200101	carta e cartone	4.943,25
200101	carta e cartone-ASS	12,43
150107	imballaggi in vetro	4.595,51
150107	imballaggi in vetro-ASS	15,23
200102	vetro	130,12
200102	vetro-ASS	23,87
150104	Imballaggi alluminio	0,31
150104	imballaggi metallici-ASS	157,37
200140	metallo	136,36
200140	metallo-ASS	21,61
150102	imballaggi in plastica	57,36
150102	imballaggi in plastica-ASS	212,31
150102	plastica	3,72
20104	teli agricoli	245,4
200139	plastica-ASS	9,94

ANNEX 4

acea PINEROLESE L'INNOVAZIONE È IL NOSTRO TERRITORIO	RELAZIONE N° Progetto IA-PEI-100-ND-RG-003		M.05.IA_REL Rev. 0 del 06/09/2010
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ALLEGATO 2

Nel corso dell'anno 2017, sono state vendute 4639 tonnellate di compost Florawiva appartenenti alla categoria ammendante compostato misto. Si è verificato un caso di compost fuori specifica per un problema sui parametri microbiologici. Tale partita, era stata conferita in discarica Acea come compost fuori specifica.

Tabella 1 Valori medi su 8 partite di compost allestite nel corso del 2017

Parametro	Valore	u.m.	Limite
Azoto organico - PARTITA Media	95,1	% Ntot p/p s.s.	
Azoto totale (come N) - PARTITA Media	2,5	% p/p s.s.	
Cadmio - PARTITA Media	0,5	mg/Kg s.s.	<1,5
Carbonio organico totale - PARTITA Media	23,6	mg/Kg s.s.	>= 20
Carbonio umico e fulvico - PARTITA Media	9,3	% s.s.	>=7
Ceneri 650 °C - PARTITA Media	52,6	% p/p s.s.	
Conducibilità a 25°C - PARTITA Media	1,8	mS/cm	
Cromo VI - PARTITA Media	0,0	mg/Kg s.s.	<0,5
Densità Media t/m3	0,7		
Escherichia coli - PARTITA Media	40,0	UFC/1 g	1000
Fosforo tot. (come P2O5) - PARTITA Media	2,2	% p/p s.s.	
Indice di Germinazione (diluizione 30%) - PARTITA Media	105,2	%	>=60
Materiali plastici, vetro e metalli (frazione > 2 mm) - PARTITA Media	0,1	% s.s.	<=0,5
Ineriti litoidi > 5 mm - PARTITA Media	1,1	% s.s.	<=5
Mercurio - PARTITA Media	0,2	mg/Kg s.s.	<=1,5
Nichel - PARTITA Media	60,1	mg/Kg s.s.	<=100
pH - PARTITA Media	8,4		da 6 a 8,8
Piombo - PARTITA Media	41,9	mg/Kg s.s.	<=140
Potassio (come K2O) - PARTITA Media	1,5	% p/p s.s.	
Rame - PARTITA Media	90,5	mg/Kg s.s.	<=230
Rapporto C/N (carbonio/azoto) - PARTITA Media	8,1		<=25
Salinità - PARTITA Media	38,3	meq/100g s.s.	
Sostanza Organica totale - PARTITA Media	47,4	% p/p s.s.	>=40
Umidità totale - PARTITA Media	42,3	% p/p s.s.	<=50
Zinco - PARTITA Media	189,1	mg/Kg s.s.	<=500

ANNEX 5

Conto economico - Riclassificazione a valore aggiunto (o della pertinenza gestionale)

	31/12/2017	Var. %	31/12/2016	Var. %	31/12/2015
Ricavi delle vendite e delle prestazioni	50.632.943	-4,22% ↓	52.865.839	40,20% ↑	37.708.057
+ Variazione rimanenze prodotti in lavorazione, semilavorati e finiti	0		0		0
+ Variazione lavori in corso su ordinazione	90.928	106,75% ↑	-1.346.243	-2.226,40% ↓	-57.868
+ Incrementi immobilizzazioni per lavori interni	770.613	-63,45% ↓	2.108.631	425,58% ↑	401.197
Valore della produzione	**51.494.484**	**-3,98% ↓**	**53.628.227**	**40,94% ↑**	**38.051.386**
- Acquisti materie prime, sussidiarie, di consumo e di merci	4.769.871	-12,76% ↓	5.467.780	40,92% ↑	3.880.124
+ Variazione rimanenze materie prime, sussidiarie, di consumo e merci	19.527	168,95% ↑	-28.319	66,41% ↑	-84.309
- Costi per servizi e per godimento beni di terzi	18.185.462	-0,03% ↓	18.191.541	2,95% ↑	17.670.217
Valore aggiunto	**28.519.624**	**-4,93% ↓**	**29.997.225**	**80,87% ↑**	**16.585.354**
- Costo per il personale	17.782.145	2,59% ↑	17.332.480	55,29% ↑	11.161.521
Margine operativo lordo (MOL/EBITDA)	**10.737.479**	**-15,22% ↓**	**12.664.745**	**133,50% ↑**	**5.423.833**
- Ammortamenti e svalutazioni	7.230.009	-7,02% ↓	7.775.911	5,41% ↑	7.376.562
- Accantonamenti per rischi e altri accantonamenti	35.230	-92,92% ↓	497.547	-66,04% ↓	1.465.109
Reddito operativo (EBIT)	**3.472.240**	**-20,93% ↓**	**4.391.287**	**228,48% ↑**	**-3.417.838**
+ Altri ricavi e proventi	3.083.446	-18,22% ↓	3.770.370	-51,68% ↓	7.802.492
- Oneri diversi di gestione	1.374.565	-13,20% ↓	1.583.523	31,36% ↑	1.205.515
+ Proventi finanziari	233.281	32,53% ↑	176.018	123,44% ↑	78.777
+ Saldo tra oneri finanziari e utile/perdita su cambi	-624.407	16,77% ↑	-750.213	14,48% ↑	-877.189
Reddito corrente	**4.789.995**	**-20,22% ↓**	**6.003.939**	**152,19% ↑**	**2.380.727**
+ Rivalutazioni di attività e passività finanziarie	0		0		0
- Svalutazioni di attività e passività finanziarie	0		0		0
Reddito ante imposte	**4.789.995**	**-20,22% ↓**	**6.003.939**	**152,19% ↑**	**2.380.727**
- Imposte sul reddito	1.554.323	-36,40% ↓	2.443.915	126,58% ↑	1.078.612
Reddito netto	**3.235.672**	**-9,11% ↓**	**3.560.024**	**173,40% ↑**	**1.302.115**