NET4mPLASTIC PROJECT

Activity 3.1

D 3.1.3

Report of waste management practices and plastic waste data in Italy and Croatia

(waste amounts, waste characteristics and management, and possible existing recycling methods for plastic marine litter)

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INDEX

1 Introduction

Plastic resins are artificial materials derived mostly from oil. Plastics are flexible, light, stress-resistant, hygienic and stable in time. In less than one century, plastics have entered in almost all productive sectors. The extreme stability in time of plastic items brings to a worrying accumulation in all environments. Items whose lifetime last for only few minutes can persist for years in the environment. Hopefully, plastics can be recycled and our society is going throughout a plastic circular economy, introducing environmental principles in legislation.

In an important report of European Union (EU) dated 2011 (Science Communication Unit, Report 2011) it is written that management of waste in the EU has been improving in terms of recycling and energy recovery, but there is still much to be done. At the heart of the problem is one of plastic's most valued properties: its durability. Combined with the throwaway culture that has grown up around plastic products, this means that we are using materials that are designed to last, but for short-term purposes.

The increased use and production of plastic in developing and emerging countries is a particular concern, as the sophistication of their waste management infrastructure may not be developing at an appropriate rate to deal with their increasing levels of plastic waste.

Plastic waste has the additional complication of spanning many policy areas, such as marine management, coastal management, waste management and the regulation of chemicals.

After seven years, the European Commission report of 2018 (European Commission, 2018) shows that in the EU, the potential for recycling plastic waste remains largely unexploited. Reuse and recycling of end-of-life plastics is very low, particularly in comparison with other materials such as paper, glass or metals. It is necessary to move towards a sustainable plastics economy; for this Europe needs a strategic vision, setting out what a 'circular' plastics economy could look like in the decades ahead.

Figure 1. An infographic diffused by Emilia Romagna Regional Environmental Protection Agency to aware the public on persistence time in sea of common-use plastic objects (ARPAE)

Waste management is one of the largest challenges in the world and one of the most demanding areas in terms of adjustment to the standards of the European Union.

The EU has set the following priority objectives for waste policy in the EU:

1. To reduce the amount of waste generated;
2. To maximise recycling and re-use;
3. To limit incineration to non-recyclable materials;
4. To phase out landfilling to non-recyclable and non-recoverable waste;
5. To ensure full implementation of the waste policy targets in all Member States.

Actual European targets for the preparation for reuse and recycling are set in Directive 2018/851 / EU: 55% in weight to be achieved by 2025, 60% by 2030 and 65% by 2035.

2 Summary of Findings

2.1 Current status of plastics cycle

Policy responses to plastic waste come in many forms and work on many levels, ranging from beach clean-ups to bans on plastic waste disposal at sea, to targets for waste management and recycling. Several market-based instruments have been explored such as deposit schemes to encourage the return and multi-use of plastics, and taxation on single-use plastics that do not fit into deposit return systems. However, there has been little widespread application of these instruments (Science Communication Unit, Report 2011).

In the academic review of Hahladakis et al., (2018) a remarkable scheme of the life cycle of plastic materials is presented (figure 1 of the review). However, a simpler representation is reported in the following figure from PlasticsEurope (2018), in which the circular economy concept is highlighted.

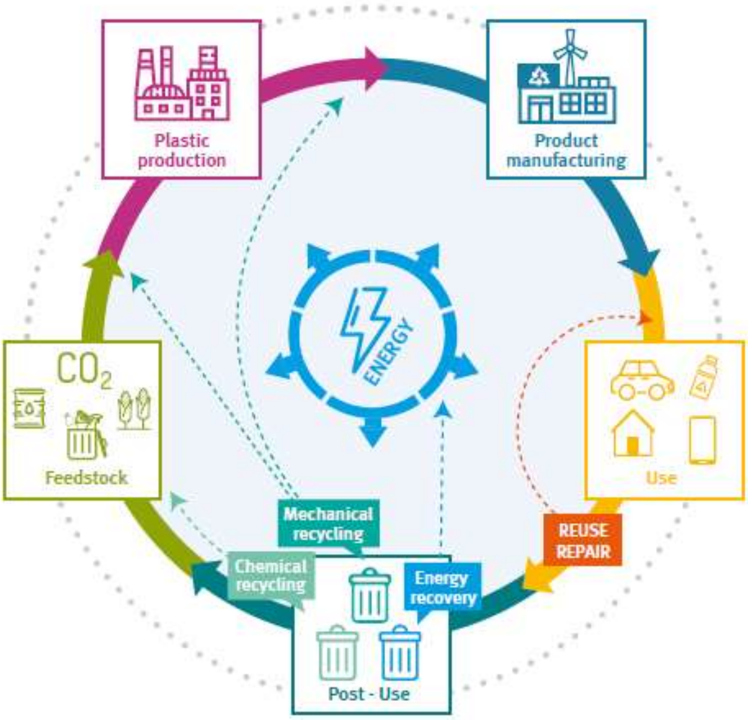


Figure 2. Circular economy concept, (PlasticsEurope, 2018)

PlasticsEurope is one of the leading European trade associations with centres in Brussels, Frankfurt, London, Madrid, Milan and Paris. They network with European and national plastics associations and have more than 100 member companies, producing over 90% of all polymers across the EU28 member states plus Norway, Switzerland and Turkey. Some of the infographics about plastic waste diffused online on the official EU website have PlasticsEurope as the source of data.

The report of PlasticsEurope (PlasticsEurope, 2018) states that from all the plastic waste generation (data unknown), the collected part (approximately 45% in 2016) went for 31% to recycling, 42% to energy recovery and 27% to controlled landfill.

The unknown part of non-collected plastics, it is possible to think that are partially disposed as municipal waste and partially abandoned in the environment (uncontrolled landfill).

Obviously, the controlled and uncontrolled landfill disposal is the worst solution.

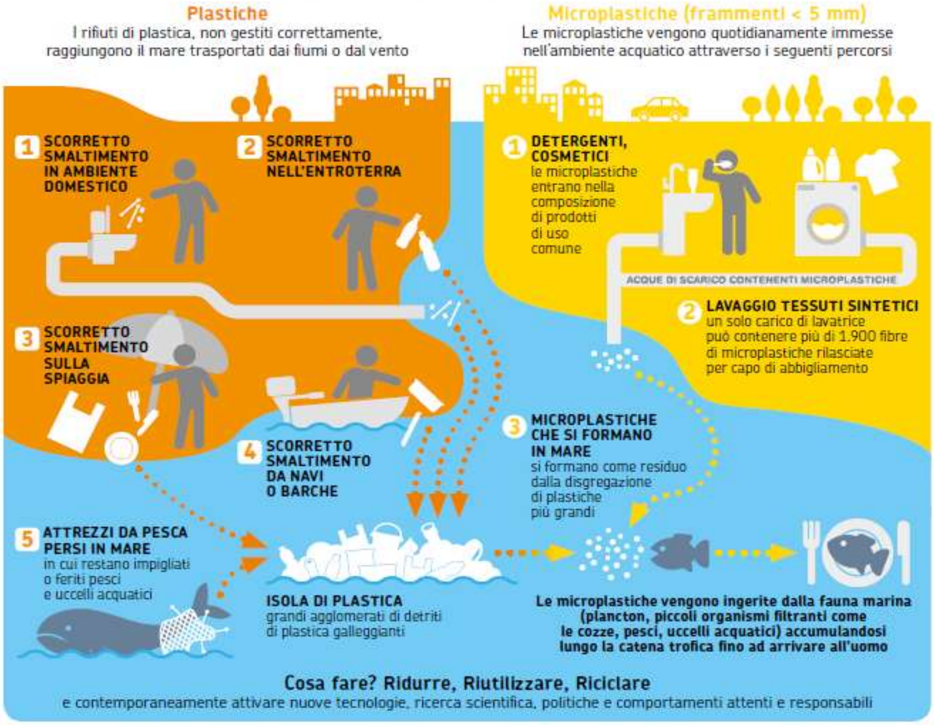


Figure 3. Uncollected plastic waste pathways in the environment (ARPAE)

Nevertheless, plastic is not a single material, but it is a wide family of materials: the high number of plastic resins makes recycling a complex operation, that starts with a complex selection.

There are many types of plastic, divided in two principal families: the first, thermoplastics, can be reheated, reshaped and frozen repeatedly, while the second, thermosets, cannot be re-melted and reformed (even if technology research is making many efforts towards this goal).

Thermoplastics

are a family of plastics that can be melted when heated and hardened when cooled. These characteristics, which lend the material its name, are reversible. That is, it can be reheated, reshaped and frozen repeatedly.

Polyethylene (PE)	Polycarbonate (PC)
Polypropylene (PP)	Poly methyl methacrylate (PMMA)
Polyvinyl-chloride (PVC)	Thermoplastic elastomers (TPE)
Polyethylene Terephthalate (PET)	Polyarylsulfone (PSU)
Polystyrene (PS)	Fluoropolymers
Expanded polystyrene (EPS)	PEEK
ABS	POM
SAN	PBT
Polyamides (PA)	EVOH
	Etc.

Thermosets

are a family of plastics that undergo a chemical change when heated, creating a three dimensional network. After they are heated and formed these plastics cannot be re-melted and reformed.

Polyurethane (PUR)	Silicone
Unsaturated polyesters	Phenol - formaldehyde resins
Epoxy resins	Urea - formaldehyde resins
Melamine resin	Phenolic resins
Vinyl esters	Acrylic resins
	Etc.

Figure 4. The two categories of plastics as proposed by PlasticsEurope (Source: Plastics – the Facts 2019. An analysis of European plastics production, demand and waste data)

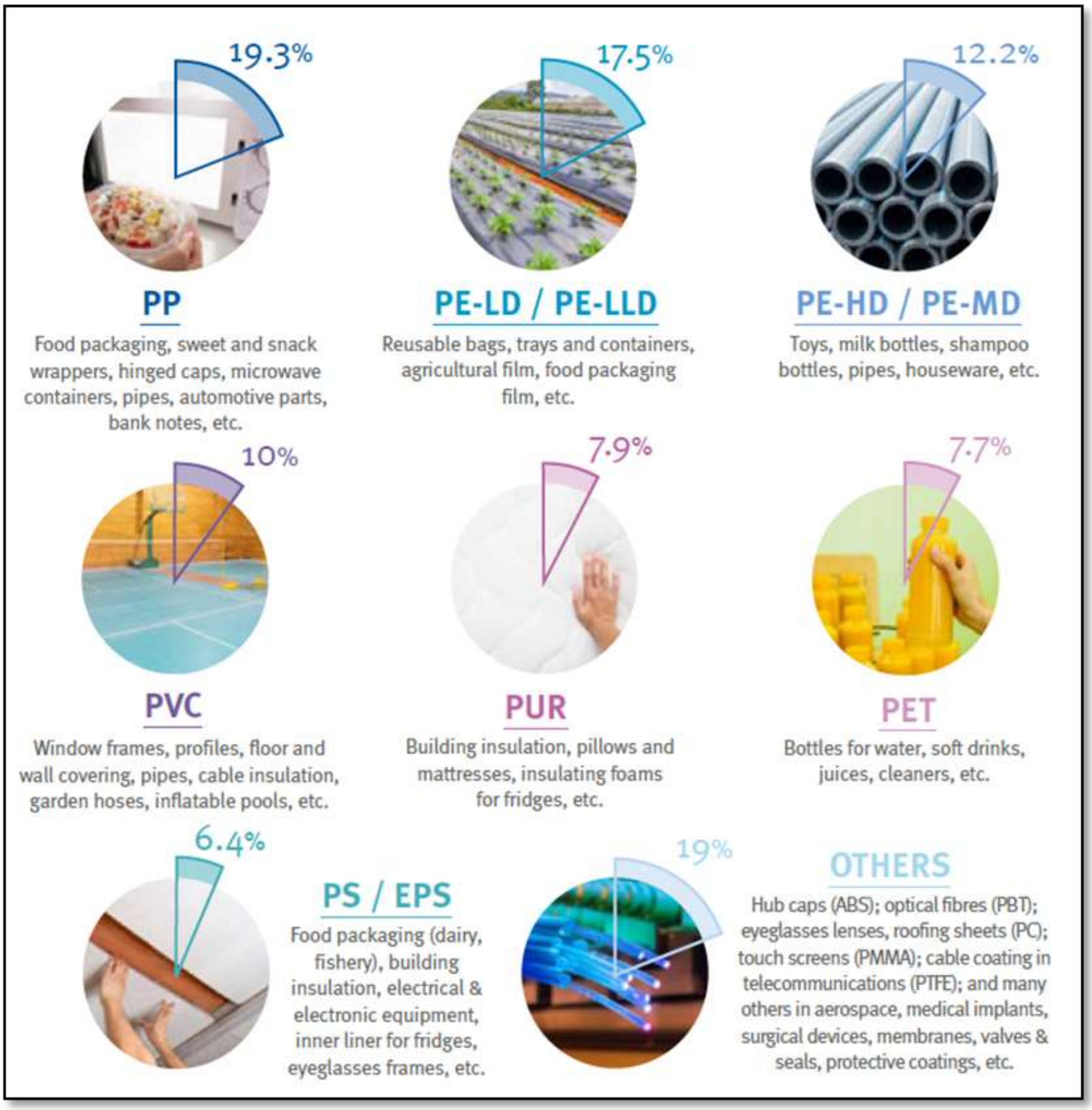


Figure 5. Plastic demand distribution by resin types 2018, data for EU28 + Norway and Switzerland. (Source: PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH)

The demand of plastic and plastic types doesn't overlap with plastic waste data, due to the variable lifetime of different plastic objects. In the following infographics, produced by PlasticsEurope, it can be compared the European plastic demand by segments and polymer types in 2018. Packaging and Building & Construction represent by far the largest end-use sectors; the third biggest end-use market is represented by the Automotive Industry. It is evident that the 3 cited sectors request different plastics and different lifetime of plastics. The service life of plastic products goes from less than one year to 50 years or more. The leading polymers requested by European market are the polyolefins PP and PE, followed by PVC, PUR and PET.

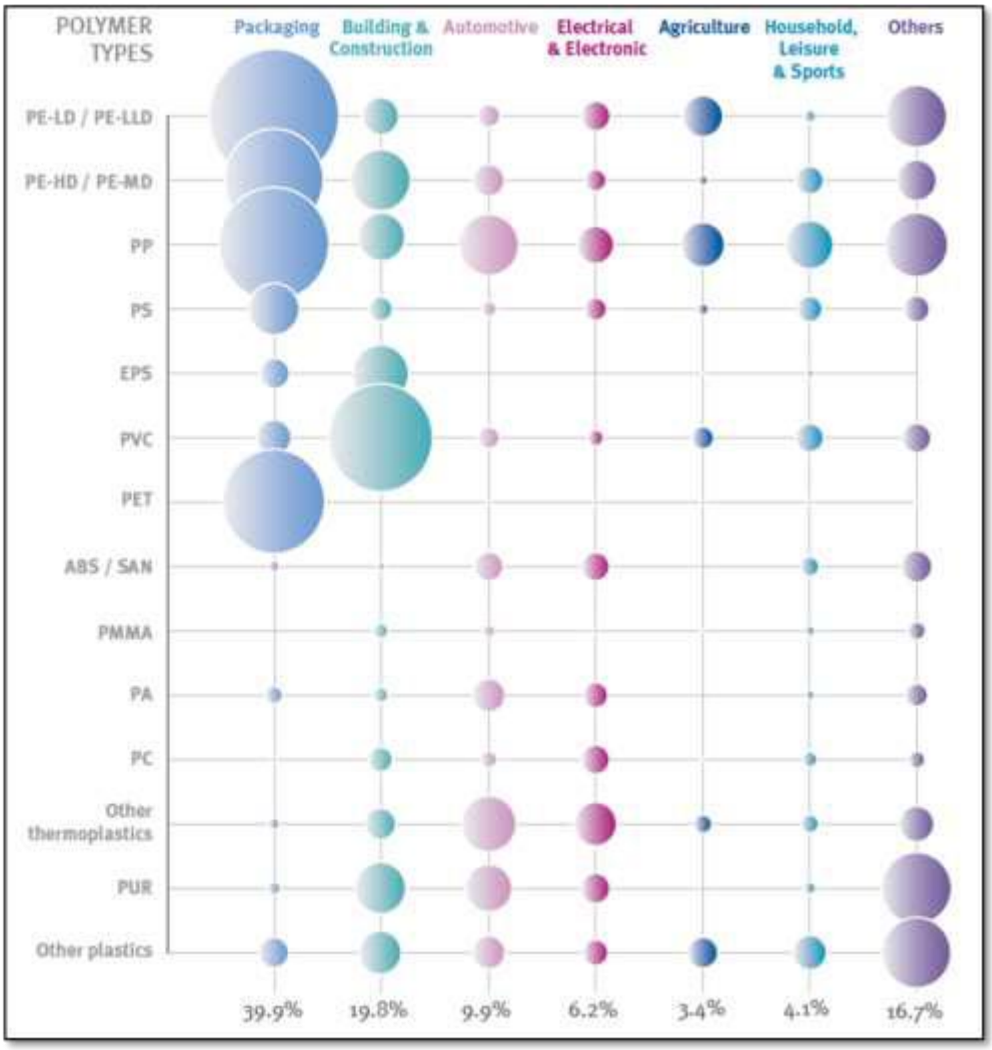


Figure 6. Plastics demand by segments and polymer types in 2018. The total amount is 51.2 million tonnes over EU28 + Norway and Switzerland. Others includes appliances, mechanical engineering, furniture, medical etc. (Source: PlasticsErops Market Research Group (PEMRG) and Conversio Market & Strategy GmbH)

The first option that can come to mind is **reuse** of plastic object. The most common examples of reuse are with glass containers, where milk and drinks bottles are returned to be cleaned and used again. Reuse is not widely practiced in relation to plastic packaging. However, there are examples of reuse in the marketplace. For example, a number of detergent manufacturers market refill sachets for bottled washing liquids and fabric softeners. Consumers can refill and hence reuse their plastic bottles at home, but in all of these cases the reusing of the plastic bottles and containers do not continue for long time especially in the food applications (Kotiba et al. 2013).

Resource recovery alternatives to landfill are **mechanical recycling**, also known as physical recycling, (primary recycling substituting virgin materials and secondary recycling); **chemical recovery** (tertiary recycling) and **energy recovery** (quaternary recycling).

The final quality of recycled material derives directly from the quality of selection of plastic waste.

Effective pre-treatment and sorting operations for waste selection save valuable resources from landfill to material for recycling and energy recovery, according with required market-driven qualities.

In primary recycling the plastic is ground down and then reprocessed and compounded to produce a new component that may or may not be the same as its original use, substituting virgin polymers (Kotiba et al. 2013); this is possible for some plastic types and fractions (e.g. for PET plastic bottles or car bumpers). However, among else, the great variability in plastics polymers and post-use contamination obstructs closed-loop recycling or makes it difficult (Hahladakis et al., 2018).

Secondary recycling is transformation of material by mechanical mean for less demanding products. The steps involved in secondary recycling are usually: cutting/shredding, contaminant separation, flakes separation by floating. After these steps single polymer plastic material is processed and milled together to form pellets (Singh et al., 2017).

Chemical recovery (tertiary recycling), involves the recovery and/or conversion of plastic into chemical substances, e.g. raw materials such as monomers. This can potentially be done by catalytic depolymerisation or by controlled *thermal degradation*, such as *thermolysis*, which is a non-catalytic cracking process. *Pyrolysis* is also considered to be a sustainable and efficient treatment that can produce a range of useful hydrocarbons, potentially used as a chemical feedstock or as energy, thereby minimizing the dependency on non-renewable fossil fuels, while solving the landfilling problem (Hahladakis et al., 2018).

The more effective ways of disposal of waste goes through quaternary recycling of waste. In quaternary recycling waste material is processed to recover energy through *incineration*, as all plastics possess very high calorific value. It also leads to volume reduction of waste and rest can be land filled (Singh et al., 2017).

In industrial countries a large share of plastic waste is used for energy recovery. In Europe, more plastics waste is destined for energy recovery (41.6%) (in waste-to-energy plants or via solid recovered fuels (SRF) recovered in cement kilns (Scalenghe, 2018)) than for recycling (31.1%) (Hahladakis et al., 2018).

The costs of collecting, sorting, and reprocessing and the low market value of the recycled plastics explain the low recycling rates globally (Scalenghe, 2018).

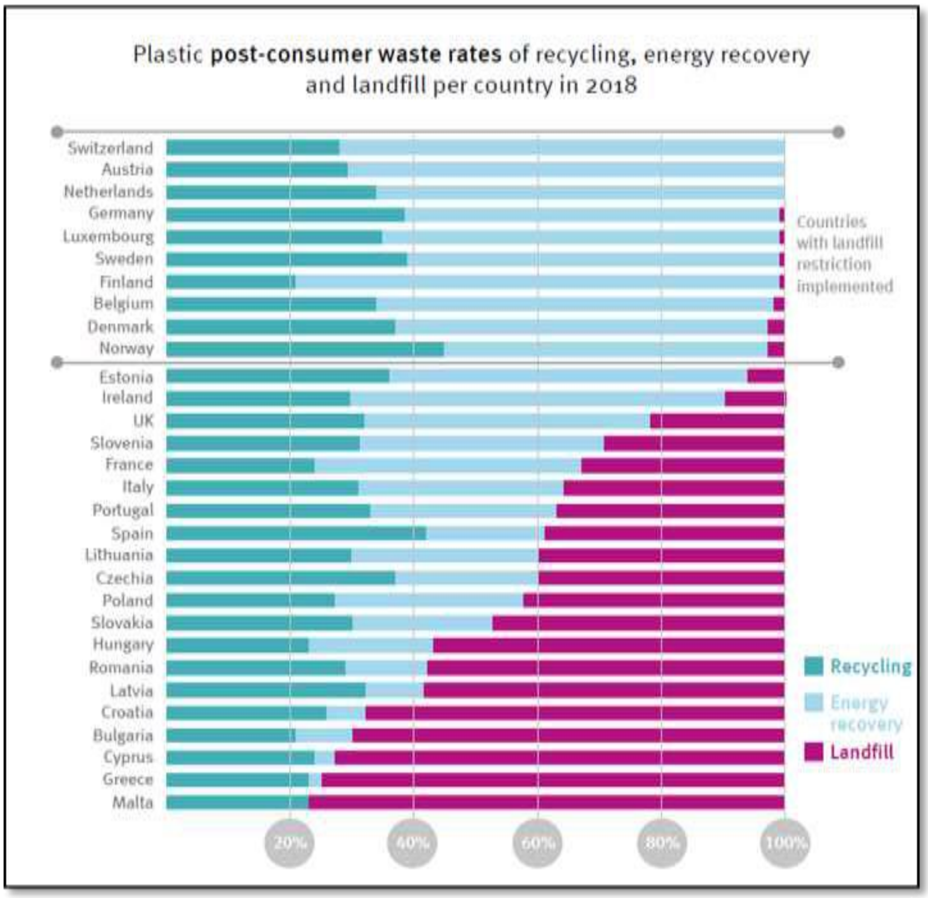


Figure 7. European Plastic post-consumer waste rates of recycling, energy recovery and landfill per country in 2018 (Source: Conversio Market & Strategy GmbH)

With technological advancements in industry all types of polymers can be recycled (Singh et al., 2017).

Some researchers have put down *three methods of recycling plastic*. First is mechanical separation of plastic waste suitable for secondary use. The second method has two further sub parts; first is energy recovery by incineration and second way is pyrolysis for use as fuels or as polymer feedstock. The third method is taking polymer up to biodegradation level, but that highly depends on type and environmental conditions (Singh et al., 2017). It is the case of so-called biodegradable materials, of which e.g. the Polylactil acid (PLA) is one of the oldest examples. It must however be taken into account that even these materials do not all have the same times and degradation methods in any environment; that is the majority is indeed biodegradable, but in special plants (composting plants).

Another trend and material flow which need also to be considered and examined is the growing production and use of biodegradable plastics (also known as bio-plastics). Whenever innovative products are developed as an alternative to conventional oil-based products, questions arise about the effective reasonable-ness of the proposed shift (Hahladakis et al., 2018).

When talking about bio-plastics, however, care must be taken, as the term includes materials that are very different from each other. With the term bio-plastic are named that plastic that derived from renewable sources (but the PE produced from sugar cane or wheat grain always remains PE), but also that there are biodegradable (compostable). So differentiation should be made on their biodegradability and not on the generic suffix "bio".

It must however be considered that when plastic undergoes a recycling process, it starts losing some of properties in terms of tensile strength, wear properties and dimensional accuracy. For this reason, there is a limited number of recycling that is possible to do. In the end, therefore, the only remaining alternatives are the landfill or incinerator (Singh et al., 2017).

The main concern about incineration regards the emissions of hazardous substances, e.g. acid gases and unintentional persistent organic pollutants (POPs) such as dioxins, that can be formed during the process. On the other hand, controlled combustion in waste-to-energy plants and cement kilns equipped with state of the art air pollution control technologies may be the best way available to limit the dispersion of POPs (Hahladakis et al., 2018).

From the report of the regional agency for environmental prevention (ARPA) of Emilia Romagna (*Biancolini et al., 2011)* on the incineration emissions is reported: “the impact on air quality of an incinerator equipped with the best technologies available and at its best is so low as to be undisputed”.

The Unites States Environmental Protection Agency (EPA website) developed the non-hazardous materials and waste management hierarchy in recognition that no single waste management approach is suitable for managing all materials and waste streams in all circumstances. The hierarchy ranks the various management strategies from most to least environmentally preferred. The hierarchy places emphasis on reducing, reusing, and recycling as key to sustainable materials management.

Source reduction, also known as waste prevention, means reducing waste at the source, and is the most environmentally preferred strategy. It can take many different forms, including reusing or donating items, buying in bulk, reducing packaging, redesigning products, and reducing toxicity. Source reduction also is important in manufacturing. Light weighting of packaging, reuse, and remanufacturing are all becoming more popular business trends. Purchasing products that incorporate these features supports source reduction.

Recycling is a series of activities that includes collecting used, reused, or unused items that would otherwise be considered waste; sorting and processing the recyclable products into raw materials; and remanufacturing the recycled raw materials into new products. Consumers provide the last link in recycling by purchasing products made from recycled content. Recycling also can include composting of food scraps, yard trimmings, and other organic materials.

Energy recovery from waste is the conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolization, anaerobic digestion, and landfill gas (LFG) recovery. This process is often called waste-to-energy (WTE). Converting non-recyclable waste materials into electricity and heat generates a renewable energy source and reduces carbon emissions by offsetting the need for energy from fossil sources and reduces methane generation from landfills. After energy is recovered, approximately ten percent of the volume remains as ash, which is generally sent to a landfill.

Figure 8. Waste management hierarchy (Source: EPA)

Prior to disposal, treatment can help reduce the volume and toxicity of waste. Treatments can be physical (e.g., shredding), chemical (e.g., incineration), and biological (e.g., anaerobic digestor). Landfills are the most common form of waste disposal and are an important component of an integrated waste management system. Modern landfills are well-engineered facilities located, designed, operated, and monitored to ensure compliance with state regulations. Landfills that accept municipal solid waste are primarily regulated by state, tribal, and local governments. The great attention in landfills design, according to the best available techniques, is becoming more and more urgent in all the World. EPA (US Environmental Protection Agency), for example, established national standards that these landfills must meet in order to stay open. The federal landfill regulations eliminated the open dumps (disposal facilities that do not meet federal and state criteria) of the past. Today's landfills must meet stringent design, operation, and closure requirements. Methane gas, a by-product of decomposing waste, can be collected and used as fuel to generate electricity. After a landfill is capped, the land may be used for recreation sites such as parks, golf courses, and ski slopes (www.epa.gov).

Plastic gathered in the sea, what to do with it

Of all the mPs in the sea, it is believed that only floating mPs can be collected effectively.

Macro plastics, of which the nature (type of polymer) and origin (e.g. fishing equipment or bottles) can be easily recognised, can be effectively disposed of in separate collection and then sent for recovery, all others must be transferred to a waste-to-energy plant.

For the thermal treatment of plastic waste, reference can be made to the technologies used for municipal solid waste.

There is a European Directive (EC, 2000) that regulates the incineration of waste (of any kind, excluding plant-related (wood), radioactive ones, those of animals and those resulting from the exploration and exploitation of oil and gas resources in offshore plants and incinerated on board of the latter). This Directive aims to avoid or limit as far as practicable the negative effects of incineration and co-incineration of waste on the environment, in particular pollution due to emissions into the atmosphere, into the soil, into surface and underground waters as well as the risks to human health that result.

This purpose is achieved through rigorous operating conditions and technical prescriptions, as well as by setting emission limit values for waste incineration and co-incineration plants in the Community, also meeting the requirements of Directive 75/442/EEC.

In waste management, incinerators are plants used for the disposal of waste through a process of combustion at high temperatures. The heat developed during combustion is recovered and used to produce steam, which is then used for the production of electricity (steam turbines) or for district heating. In this case more correctly we talk about waste-to-energy plants.

According to the review of Beyene, Werkneh, & Ambaye (2018), the promising waste-to-energy (WtE) conversion technologies are thermal conversion methods (incineration, pyrolysis, and gasification), biochemical conversion, and landfill.

Electricity, heat, fuel gases, liquids, and solids are the primary recovery products of those technologies. In practice, combinations of two or more of these methods may be used.

Incineration is a technique essentially applied by waste combustion in a furnace by monitoring burning at high temperatures which takes place between 750 and 1100°C. The aim of this technique is the degradation of organic matter present in municipal solid waste (MSW), with the presence of oxygen. In this way there is a decrease of weight and the volume of MSW with production of heat and energy. It is capable of reducing the almost 70% of the total waste mass and 80-90% of total volume depending on composition and degree of recovery of certain materials like metals from the ash. Energy efficiency for heat production, cogeneration (steam and electricity) and electricity alone is 80%, 20-30% and 20% respectively.

Pyrolysis is a thermal decomposition of materials in the absence of oxygen at the range of temperature 300–1300°C. The three common types of pyrolysis methods are conventional pyrolysis (280–630°C), fast pyrolysis (580–900°C), and flash pyrolysis (780–1030°C). The reaction products are a gaseous product, a pyrolytic liquid, and char, with ash as an undesirable residue. The common pyrolysis reactors are fixed-bed, rotary kiln, fluidized-bed and tubular reactors, but rotary kilns and tubular reactors are conveniences at large scale.

Gasification is a third method thermo-chemical transformation of MSW into hydrocarbon gases (hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and low molecular weight hydrocarbons), hydrocarbon liquids (oils) and char (carbon black and ash); the reaction take place at high temperatures (800– 1200°C), without combustion, with a controlled amount of oxygen and/or steam. Reactor design and operating parameters of gasification process also generate other higher hydrocarbons (HC) besides CH_4. Coal, petroleum-based materials, and organic based materials are usually raw materials used in gasification.

2.2 The Italian situation

To fully understand the different steps of plastic circular economy in Italy, it is due an introduction to municipal waste volumes, focusing on plastic waste and its predominant part, i.e. packaging. Italian system of plastic packaging waste prevention, collection and selection is explained, with and analysis of its volumes (actual situation, past ten years trend and forecasts for the future years). A description of plastic waste management out of municipal circuit is also presented, followed by a geographical description of Italian plastic waste treatment plants.

In Italy the latest available national data of municipal waste (Rifiuti Urbani - RU) are referred to 2018, collected, analysed and published by ISPRA in 2019. Italian national database (Catasto Rifiuti) collects and organises information on production, collection and management costs up to municipal details, as well as information about treatment plants. There is no a National waste collection scheme, but every municipality has its own municipal waste collection scheme, collecting organic waste, plastics, paper, metal, glass, gardening and other items. Some schemes collect plastics waste alone; others collect plastics together with other materials in order to be aligned with downstream infrastructure for pre-treatment, sorting, and recovery to maximise recovery, manage costs and improve environmental performance.

The national municipal waste production stands at almost 30.2 million tons. Referring to a longer period of time, between 2006 and 2010 municipal waste production remained constantly above 32 million tons, contracting with a sharp drop in 2011-2012 period (concomitant with the contraction of gross domestic product and consumption values), at a tonnage between 29.5 and 30.2 million tons. This information should be read with the continuous efforts of the legislation to reduce waste production.

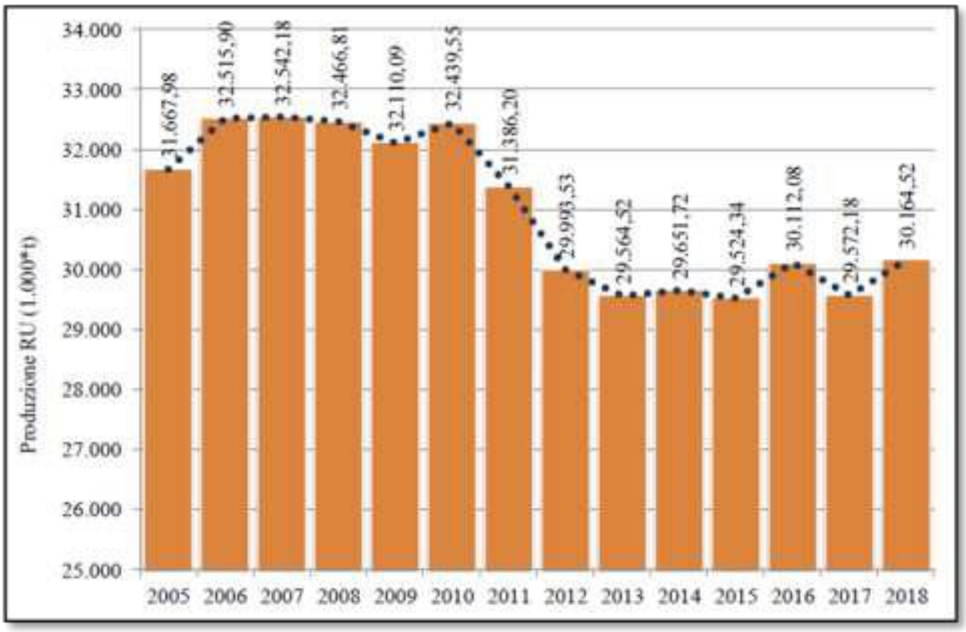


Figure 9. Italian municipal waste production trend, years 2005-2018 (Source: ISPRA, 2019)

Municipal waste production *pro capite* differs along Italy, showing higher waste production kg/inhabitant in central Italy and less production in south Italy. Although, due to the different population concentration along the peninsula, almost half of the tonnage is produced in northern regions, almost one third in the southern, and the remaining in the central once. Data concerning the percentage of separate waste collection are produced as well: 58,13% is the national percentage of separate waste collection, unifying the 67,71% collected in the northern macro area, the 54,12% collected in the central and the 46,14% collected in the southern part of Italy.[1]

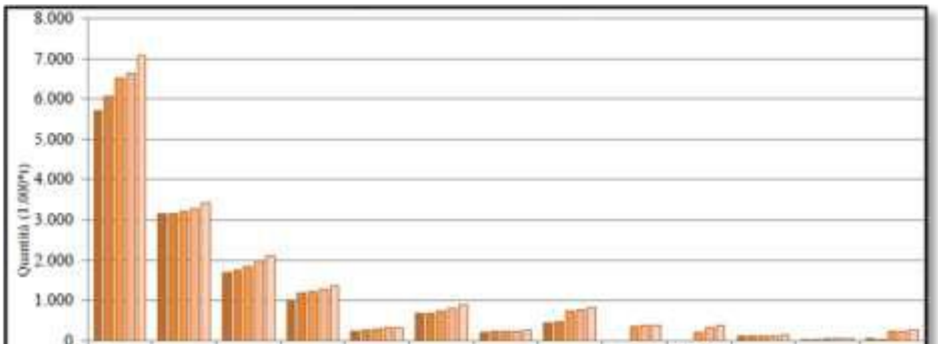
Table 1: Production and separate collection of municipal waste for Italian geographic macro-area - 2018 (ISPRA)

Area	Population (number inhabitants)	Selected Waste (t)	Municipal Waste (t)	Percentage Selected Waste (%)	*Pro capite* Selected Waste (kg/inhabitant *year)	*Pro capite* Municipal Waste (kg/inhabitant *year)
North	27.746.113	9.708.633,33	14.338.478,44	67,71	349,91	516,77
Centre	12.016.009	3.561.985,88	6.581.902,40	54,12	296,44	547,76
South	20.597.424	4.264.781,87	9.244.134,72	46,14	207,05	448,8
ITALY	60.359.546	17.535.401,09	30.164.515,55	58,13	290,52	499,75

The Waste Framework Directive 2008/98/EC expected that, by 2020, the preparation for the reuse and recycling of waste had increased overall at least 50% in terms of weight. The concerned waste materials are, at the very least, paper, metals, plastics and glass from households, and possibly of other origin if similar to domestic waste streams. The framework directive has been widely amended by Directive 2018/851 / EU, which added additional targets for the preparation for reuse and recycling: 55% in weight to be achieved by 2025, 60% by 2030 and 65% by 2035. It can be noted from the table above that northern Italy, on average, has reached the goal fixed for year 2035, central Italy has reached the goal for 2020 and southern Italy has not yet achieved the 50% in terms of weight.

The subdivision of waste weight in waste types, illustrated in the following histogram, is of particular interest.

[1] North Italy: Piemonte, Valle d'Aosta, Lombardia, Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Liguria, Emilia-Romagna. Central Italy: Toscana, Umbria, Marche, Lazio. South Italy: Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicilia, Sardegna



	Frazione organica	Carta	Vetro	Plastica	Metallo	Legno	RAEE	Ingomb. misti	Rifiuti da C&D (1)	Spazz. stradale a rec. (1)	Tessili	Selettiva	Altro (2)
2014	5.720,0	3.153,9	1.691,3	1.012,5	249,6	676,0	213,7	447,3			124,4	40,6	72,2
2015	6.071,5	3.149,9	1.747,8	1.178,0	261,1	695,3	222,9	484,3			129,0	42,4	38,6
2016	6.516,9	3.218,9	1.852,4	1.234,0	293,1	739,5	234,8	754,2	350,3	215,5	133,3	43,9	235,7
2017	6.621,6	3.276,9	2.000,3	1.273,6	316,8	800,4	240,3	773,0	385,9	311,3	133,4	46,4	245,3
2018	7.079,8	3.418,2	2.118,5	1.368,0	332,1	908,4	255,9	826,1	390,3	371,0	146,2	48,6	272,3

Figure 10. Italian separate collection by waste type, years 2014-2018 (Source: ISPRA). Different item are, from left to right: Organic fraction (organic and gardening), Paper and cardboard, Glass, Plastic, Metals, Wood, Electrical and Electronic Appliances (E-Waste), Mixed Bulky, Construction and Demolition Waste, Street Sweeping, Textile, Selective, Other[2][3]

A crucial fact is that over selected waste, more than the half is composed by packaging, as illustrated by the blue column in the following histogram. The 5 orange columns describe the percentage of packaging sorted by waste material. The overwhelming majority of plastic waste consists in packaging, and almost 9 over 10 tonnes of glass waste are packaging as well. Metal packaging covers the 44% of total metal waste collected. Paper and cardboard are found to be one third from packaging, and as latter wood used as packaging represent one fifth of the total wood collected.

[2] Waste types included from 2016 with the Ministerial Decree of 26 May 2016

[3] The item "Altro" ("other" in Italian) also includes, from 2016, waste from the multi-material collection. Based on the criteria established by the Ministerial Decree of 26 May 2016, the latter must, in fact, be fully computed (gross of the waste share) in the Selected Waste data. The quotas for the fractions paper (Carta), glass (Vetro), plastic (Plastica), metals (Metallo) and wood (Legno) are given by the sum of the collected quantities of packaging and other types of waste made up of these materials.

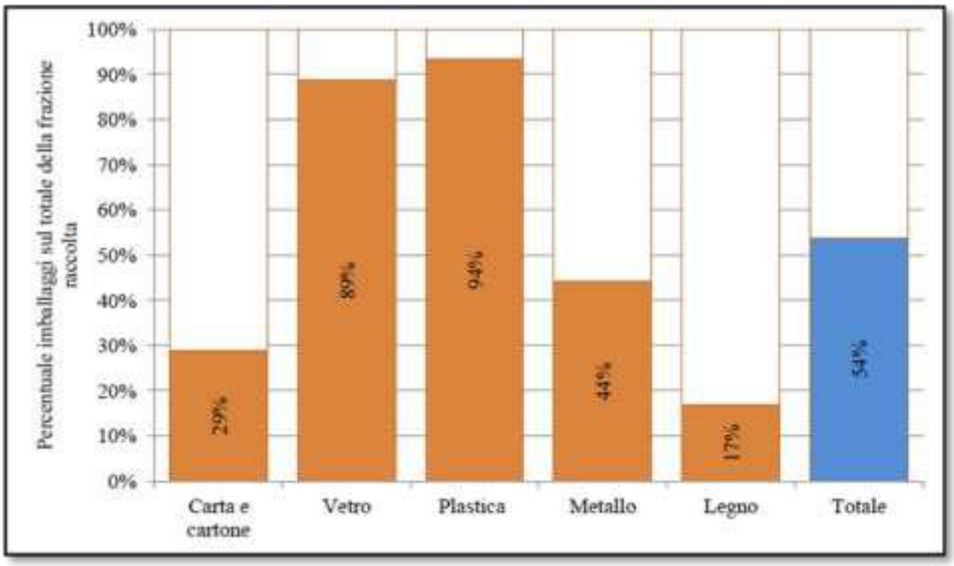


Figure 11. 2013-2018 average percentage of packaging waste out of the total collection of individual waste types. From left to right: Paper and cardboard, Glass, Plastic, Metals, Wood (Source: ISPRA)

In order to regulate the big sector of packaging collection and recycling, an official Framework Agreement has been implemented between ANCI and CONAI (ANCI[4] is the National Association of Italian Municipalities and CONAI is National Consortium of Packaging). This model is based on the principle of "shared responsibility", involving all players in waste management: from the companies that produce and use packaging, to the Public Administration, which establishes the rules for waste management on the territory, to the citizens, who collect waste separately every day, up to the companies that recycle. Since the municipalities, with waste separation scheme, have increased the cost of waste collection, the ANCI-CONAI Framework Agreement is the instrument through which the coverage of the greater costs is guaranteed: the CONAI consortium system collect from its 800.000 members a certain sum of money, calculated on the packaging quantity every member is going to put in commerce. ANCI Italian municipalities operate the collection and communicate the amount of selected waste collected, and CONAI consortium allocates money to the municipality according to quantity and quality of selected waste given to waste treatment plans. The ANCI-CONAI Framework Agreement has been required by the law Ronchi Decree of 1997 and then by Legislative Decree 152/06. CONAI is a private stakeholder and is not the only consortium in Italy, but is the biggest one with over 7.000 municipalities affiliated, 800.000 member companies and 57 million citizens served by the conventions. The current Framework Agreement 2014-2019 is going to be renovated and it will be defined before 30 April 2020. In the Agreement it is stated that municipalities can leave it, within a previously defined window of time, sending the collected material directly to recycling. CONAI stated that in 2018 an amount of 80.6% of packaging put in commerce has been collected and the 69.7% has been recycled.

[4] ANCI Associazione Nazionale Comuni Italiani – National Association of Italian Municipalities - www.anci.it
CONAI Consorzio Nazionale Imballaggi – National Consortium of Packaging - www.conai.org

Table 2. Conventions signed in ANCI-CONAI Framework Agreement. Waste materials up to 31 December 2018: steel, aluminium, paper, wood, plastic, glass. On the first line: Material, Number of affiliated subjects, Number of inhabitants, % of covered population, Number of municipalities, % of covered municipalities (Source: CONAI)

Material	Affiliated subjects	Inhabitants	% of population covered	Municipalities	% municipalities served
Steel	461	51.813.502	86%	5.970	75%
Aluminium	378	44.246.392	73%	5.174	65%
Paper	914	49.700.000	81%	5.506	68%
Wood	356	42.115.759	69%	4.541	57%
Plastic	980	57.781.901	95%	7.231	91%
Glass	522	57.904.000	93%	7.212	91%

The CONAI system is based on the activity of six consortia representing the main materials used for packaging: steel (Ricrea), aluminium (CiAl), paper and cardboard (Comieco), wood (Rilegno), plastics (Corepla), glass (CoReVe). Each of these has a specific CAC (CONAI environmental contribution), depending on the different costs of collection, selection and recycling processes. CAC are calculated with
the aim to encourage the use of more recyclable packaging, linking the contribution level to the environmental impact of the end of life / new life phases.

Figure 12. The 6 material families collected by the 6 consortiums of CONAI (Source: CONAI website)

Focusing on plastics, the consortium Corepla[5] (National consortium for collection, recycling and recovery of plastic packaging) has set 3 ranges of cost, depending on the complexity of selecting, recycling and recovery activities:

[5] Corepla - Consorzio Nazionale per la raccolta, il riciclo e il recupero degli imballaggi in plastica - www.corepla.it

1. RANGE A - selectable and recyclable packaging from the "Commerce & Industry" circuit: € 150.00/t
2. RANGE B:
   - RANGE B1 - packaging from the "Domestic" circuit with an effective and consolidated selection and recycling chain: € 208.00/t
   - RANGE B2 - other packaging selectable and recyclable from the "Domestic" circuit: € 263.00/t
3. RANGE C - non-selectable / recyclable packaging in the current state of technology: € 369.00/t.

In Italy 33 CSS (Storage Selection Centres) are able to select up to 15 products, among standards and experimental. 98% of produced volumes are selected with automatic technologies. These 33 operators do not work exclusively with Corepla.

Figure 13. Location of the 33 Italian CSS - Storage Selection Centres (Source: Corepla)

Previsions for the next years are shown in the following tables, extracted from Corepla Program for Specific Prevention 2019-2013. Tables describe general volumes of plastics put into commerce and recycled, an insight of forecasted volumes over the 5 more common plastic types, and the volumes forecasted for energy recovery.

	2018	2019	2020	2021	2022	2023
IMMESSO AL CONSUMO	**2.292.000**	**2.317.000**	**2.345.000**	**2.378.000**	**2.414.000**	**2.450.000**
RICICLO COREPLA	643.544	691.000	734.000	769.000	808.000	847.000
RICICLO INDIPENDENTE	376.000	379.000	382.000	386.000	390.000	394.000
TOTALE RICICLO	**1.019.544**	**1.070.000**	**1.116.000**	**1.155.000**	**1.198.000**	**1.241.000**
Incidenza %	***44,5%***	***46,2%***	***47,6%***	***48,6%***	***49,6%***	***50,7%***
RECUPERO ENERGETICO COREPLA*	383.057	507.000	572.000	640.000	698.000	739.000
RECUPERO ENERGETICO RSU	603.360	573.000	533.000	488.000	438.000	383.000
TOTALE RECUPERO ENERGETICO	**986.417**	**1.080.000**	**1.105.000**	**1.128.000**	**1.136.000**	**1.122.000**
Incidenza %	***43,0%***	***46,6%***	***47,1%***	***47,4%***	***47,1%***	***45,8%***
RECUPERO TOTALE	**2.005.961**	**2.150.000**	**2.221.000**	**2.283.000**	**2.334.000**	**2.363.000**
Incidenza %	***87,5%***	***92,8%***	***94,7%***	***96,0%***	***96,7%***	***96,4%***

PRODOTTO	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
PET	244.809	255.000	264.000	273.000	282.000	290.000
HDPE	69.967	71.000	73.000	74.000	76.000	77.000
FILM	84.608	94.000	103.000	113.000	123.000	134.000
PLASTICHE MISTE	212.245	231.000	254.000	269.000	287.000	306.000
SRA	4.549	10.000	10.000	10.000	10.000	10.000
TOTALE	**616.178**	**661.000**	**704.000**	**739.000**	**778.000**	**817.000**

	2018	2019	2020	2021	2022	2023
RECUPERO ENERGETICO COREPLA	**472.906**	**619.000**	**700.000**	**785.000**	**860.000**	**925.000**
di cui Imballaggi	*383.057*	*507.000*	*572.000*	*640.000*	*698.000*	*739.000*
di cui Frazione estranea	*89.849*	*112.000*	*128.000*	*145.000*	*162.000*	*186.000*
RECUPERO ENERGETICO RSU	**603.360**	**573.000**	**533.000**	**488.000**	**438.000**	**383.000**
TOTALE RECUPERO ENERGETICO	**1.076.266**	**1.192.000**	**1.233.000**	**1.273.000**	**1.298.000**	**1.308.000**
MATERIALE in DISCARICA	**110.395**	**64.000**	**61.000**	**58.000**	**55.000**	**52.000**

*Figure 14. Prospect for the near future Corepla and other operators' volumes in tonnes and percentages. From the top to the bottom: volumes put into market, expected quantities recycled by Corepla and other operators, energy recovery by Corepla (*Net of the foreign fraction) and by Municipal Solid Waste; focus the forecasted recycled volumes for the 5 more common plastic types; focus on the energy recovery by Corepla (packaging and foreign fraction), by Municipal Solid Waste and volumes put into landfills (Source: Corepla)*

Not every type of plastic is recycled. These previsions don't take into account the so-called PLASMIX, the residual substance deriving from the selection of plastic packaging. A worsening of plastic collection quality and a decrease in the volumes available for energy recovery in Italian waste-to-energy plants, or even the lack of spaces available to safely store PLASMIX, has intensified a commercial activity towards foreign cement factories operating, for example, in Germany, Austria, Greece and Bulgaria. Plastics Europe notes that "countries with landfill restrictions of recyclable waste have, on average, higher recycling rates of plastic post-consumer waste".

Nevertheless, Italy is playing a positive battle towards circular economy, as resumed by the following infographics that show the trend of 10 years plastic waste treatment in Italy. From 2006 to 2016, the volumes of recycling plastic increased by 46%, the volumes of energy recovery by 53%, while the landfilling volumes decreased by 49%. Between the 3.4 million tonnes of plastic post-consumer waste collected in 2016, 2.2 million tonnes were packaging collected in order to be treated, increasing in 10 years by 41% in volumes sent to recycling and decreasing by 66% the volumes sent to landfill.

Figure 15. Trend of plastic packaging waste treatment in Italy as presented by PlasticsEurope in the annual analysis of European plastics production, demand and waste data (Source: PlasticsEurope)

Another big set of data that are not taken into account in the previous previsions are plastic derived from industrial, commercial and agricultural activities. Many of these plastics are managed by PolieCo[6] (National consortium for the recycling of polyethylene goods) that treats, for example, greenhouses films, large crates used in agriculture, small tanks purchased empty to be filled and emptied as part of the production / commercial activity, useful element or equipment in the production process and internal or external logistics between producers.

[6] PolieCo – Consorzio nazionale per il riciclaggio di rifiuti di beni in polietilene - www.polieco.it

ISPRA has calculated the percentage origin of plastic waste produced in Italy in 2016, showed in the following scheme. In 2016 the total amount of plastic put into market has been about 5 million tonnes. Compared to the total plastic waste produced, only 40% is sent to recycling (31% packaging waste and 9% other plastic waste). With reference to packaging waste only, the percentage of recycling exceeds abundantly the current European and national target. Although it is clear that one substantial share of plastic waste is not inscribed in a correct enhancement circuit.

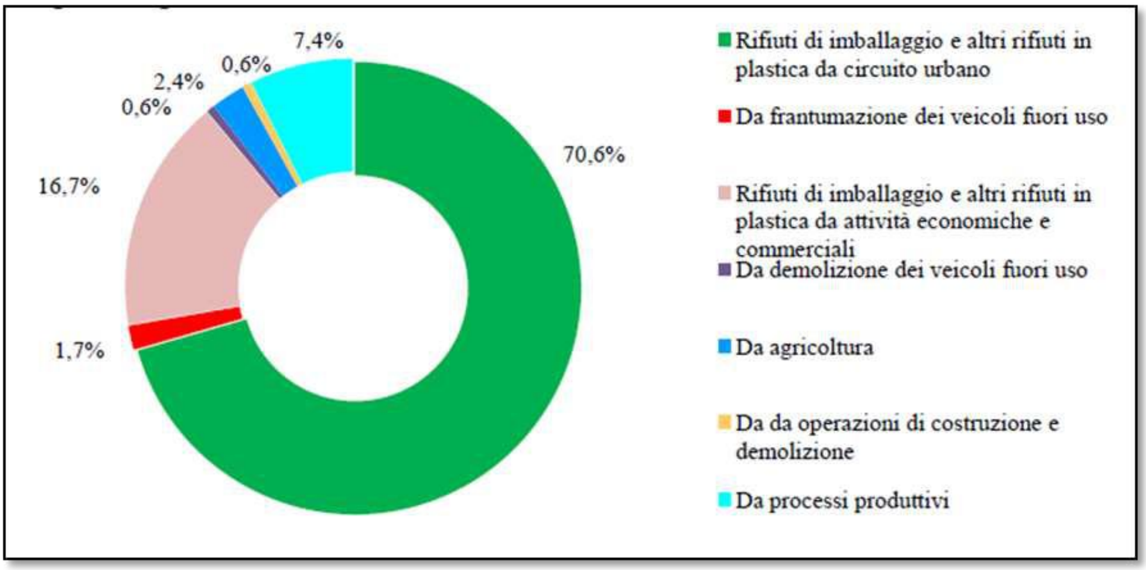


Figure 16. Percentage distribution of plastic waste produced nationally by sector of origin, 2016. From the top to the bottom: packaging waste and other plastic waste from urban collection; end-of-life vehicles crushing; packaging and other plastic waste from economical and commercial activities; end-of-life vehicle demolition; agriculture; construction and demolition operations; production processes (Source: ISPRA)

In Italy there are 579 plants able to receive for free packaging waste from the industrial, commercial, craft and industrial enterprises of services, outside the public service of collection.

Figure 17. Localisation of municipal waste treatment plants – all plants, 2018. Dark green – compost; light green – aerobic/anaerobic integrated treatment; yellow – anaerobic digestion; red – mechanical biologic treatment; blue – incineration; violet – co-incineration; black – landfill. (Source: ISPRA)

In the previous chart, treatment plants are shown together with waste-to-energy plants and landfills. The optimal solution for plastic waste should never be landfill, as required by European indications. Zero landfilling is needed to achieve the circular economy of plastics. In Italy 74 treatment plants are dedicated to plastic alone (28) or plastic and other materials (46), this is over 646 treatment plants distributed on national territory, on which 127 are landfills. Incineration (38 plants) and co-incineration (11 plants) are not able to absorb all PLASMIX produced in the selection process.

Table 3: Territorial distribution of eco platforms working with plastic for Italian geographic macro-area - 2018 (Source: ISPRA elaboration from CONAI data)

Area	**Plastic**	**Paper and Plastic**	**Wood and Plastic**	**Steel and Plastic**	**Paper, Wood and Plastic**	**Total at 31/12/2018**
North	17	2	5	25	2	51
Centre	5	0	2	2	1	10
South	6	3	3	1	0	13
ITALY	28	5	10	28	3	74

Regarding the landfill regulation, in Italy the provisions of art. 182-bis of Legislative Decree no. 152/2006 provides for the realization of self-sufficiency in the disposal of non- hazardous urban waste and waste from their treatment through the construction of an integrated plant network in the optimal territorial area (ISPRA, 2017).

So, the ideal best practice would be:

- to reduce the disposable plastic
- to separate waste collection
- to recycle
- to energy recovery

Plastic in the sea – Italy situation

The first problem of the plastics (macro-, meso- and micro-) in water deals with the possibility to gather it. Until now, due to different and contradictory regulations, the waste caught by fishermen was considered special waste and not urban waste.

In Italy some actions have been recently taken.

On April 4, 2019, the "Salvamare" (sea safe law) bill was approved by the Council of Ministers, according to which the fishermen will be able to bring the accidentally fell plastic into the nets without penalties, but they will be recognized an environmental certification. At the moment we are awaiting the passage of this law in Parliament (Presidenza del Consiglio dei Ministri, 2019).

The navy of San Benedetto del Tronto (in the Marche Region) has started a project to clean the seas called "Plastic fishing" (A Pesca di Plastica). Thanks to the fleet equipped for trawling, 40 fishing vessels will begin to land not only fish but also the waste trapped in the nets, which will be analyzed and sent for recycling or disposal. The 30-day project ended June 3, 2019.

2.3 The Croatian situation

The National Waste Management Strategy of Croatia (2007-2015) assesses the situation, identifies the problems and obstacles and sets the main waste management objectives for the period 2005-2025. These goals include:

- – Development of an integrated waste management system;
- – Establishment of county and regional waste management centres;
- – Remediation and closure of existing landfills;
- – Remediation of sites highly polluted by waste – hot spots;
- – Improved information and reporting systems for the waste management system.

The Waste Management Strategy regulates the management of different types of waste on the territory of the Republic of Croatia, from its generation to final disposal, with the basic aim of achieving and maintaining an integrated waste management system, which will be organized in line with contemporary European requirements and standards (https://mzoip.hr/doc/waste_management_plan_og_85-207.pdf).

The Waste Management Strategy is implemented through a National Waste Management Implementation Plan, which was adopted on 19th July 2007 by the Government of the Republic of Croatia and was valid for a period of 8 years. The Waste Management Plan of the Republic of Croatia for the period 2017-2022 was adopted in January 2017 (https://www.mzoip.hr/en/waste/strategies-plans-and-programmes.html).

These general goals in waste management should be accomplished according to the Waste Management Plan:

- separating economic growth from the increase of waste quantities;
- guarding natural resources;
- decreasing the total mass of landfilled waste;
- decreasing the emissions of polluting matters in the environment;
- decreasing the hazard for human health and the environment (MZOIP 2017).

All Croatian regulations and legislations related to waste management can be found in http://www.azo.hr/Default.aspx?art=996&sec=536 and on http://www.lexadin.nl/wlg/legis/nofr/eur/lxwecro.htm.

It is expected that in 2025 almost the entire population of Croatia will be included in the organized collection of a municipal waste system, recycled and treated waste will grow significantly, and an important reduction of disposed municipal and biodegradable waste will be achieved.

Currently municipal waste management in Croatia is undergoing a radical transformation from decentralized disposal of non-treated waste on numerous local sub-standard landfills within counties to centralized waste management and Waste Management Centres (WMC) serving the needs of one county or, in some cases, of several counties. The WMC concept has been adopted by the Croatian Government in its National Waste Management Plan.

In Croatia, the most used waste practices are:

- Recycling;
- Physical Reprocessing;
- Composting;
- Energy Recovery;
- Incineration;
- Landfill.

The most common consumer products recycled include aluminium beverage cans, steel food and aerosol cans, HDPE and PET bottles, glass, and jars, paperboard cartons, newspapers, magazines, and cardboard. Other types of plastic (PVC, LDPE, PP and PS) are also recyclable, although these are commonly collected. Croatia needs to increase the amount of recycled material.

In 2014 the total reported quantities of produced waste (municipal and production waste) were around 3.7 million tonnes which is a 10.5% increase compared to 2012. Of the total amount of waste, nonhazardous waste constitutes 97%, while hazardous waste constitutes the remaining 3%.

The Act on Sustainable Waste management (hereinafter: ASWM) (OG 94/13) defines municipal waste as waste produced in households and waste which is in its nature and composition similar to household waste, excluding production waste and agriculture and forestry waste. Mixed municipal waste is waste from households and waste from stores, industry and institutions which is in its properties and composition similar to household waste, and which has not been subjected to special procedures of extraction of certain materials (e.g. paper, glass etc.) and carries the code 20 03 01 in the Waste catalogue (Ordinance on the waste catalogue, OG 90/15).

In Republic of Croatia the latest available data of municipal waste are referred to 2018, collected, analysed and published by Ministry of Environment and Energy (MZOE) in 2019. Information on production of municipal wastes, its collection and management are collected and stored in Croatian national database (Registar onečišćavanja okoliša – ROO), as well as information about treatment plants. Same as in Italy, in Croatia every County has its own municipal waste collection scheme, collecting organic waste, plastics, paper, metal, glass, gardening and other items.

During the 2017 a total of 130 waste landfills were active in Croatia. There were 116 active waste disposal sites and 197 companies that collected municipal waste in 2018. There were 1.768.411 t of municipal waste produced in 2018. Municipal waste production *pro capite* for the year 2018 equals 432 kg, that is 1,2 kg *pro capite* per day in the same year. The public service of collecting municipal waste in 2018 was utilized by 99% of the population in the Republic of Croatia. The percentage of the mixed municipal waste (the code 20 03 01 in the Waste catalogue) makes 69% of municipal waste produced in 2018.

Table 4. Municipal waste management in Croatia in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode)

	Generated	Separately collected	Recycling	Recycling – composting and digestion	Recovery – incineration (R1)	Disposal - incineration D10	Disposal
Total quantity	1.768.411	553.791	398.381	48.648	1.042	3,57	1.170.912
Total quantity %		31,3%	22,5%	2,8%	0,06%	0,0002%	66,2%

If we take a look at the years before, we see constant growth of total amount of municipal waste produced annually from 1995. to 2018. As it is visible from these numbers, the national municipal waste production stands at almost 1.8 million tons for the last 10 years.

Table 5. The annual amounts of municipal waste generated in Croatia for the period of 1995. to 2018 (Source: MZOE, Zavod z zaštitu okoliša i prirode)

Year	Amount of municipal waste (t)
1995.	978.542
1997.	1.015.000
2000.	1.172.534
2004.	1.310.643
2005.	1.449.381
2006.	1.654.105
2007.	1.718.697
2008.	1.788.311
2009.	1.743.211
2010.	1.629.915
2011.	1.645.295
2012.	1.670.005
2013.	1.720.758
2014.	1.637.371
2015.	1.653.918
2016.	1.679.765
2017.	1.716.441
2018.	1.768.411

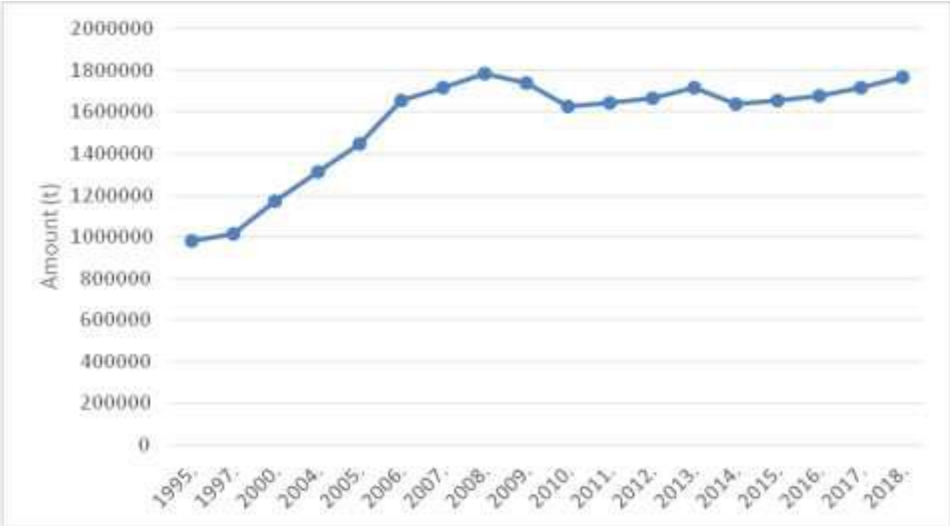


Figure 18. Croatian municipal waste production trend, years 1995-2018 (Source: MZOE)

Significant amount of municipal waste comes from tourism. The quantity of municipal waste from tourism has grown from 2014 to 2018 for 86% as a result of greater number of overnight stays in 2018. The largest quantities of municipal waste from tourism are produced in the county of Istria, the county of Split-Dalmatia and the county of Primorje-Gorski Kotar, while the smallest quantities are reported in the county of Virovitica Podravina and the Požega Slavonija county.

Table 6. The quantity of municipal waste from tourism in the period 2014.-2018. (Source: MZOE, Zavod za zaštitu okoliša i prirode)

Year	The quantity of municipal waste from tourism (t)	Portion of municipal waste from tourism in total amount of produced municipal waste (%)	The Inhabitant Equivalent
2014.	88.844	5,4	232.576
2015.	98.960	6,0	256.374
2016.	139.535	8,3	355.956
2017.	155.958	9,1	374.899
2018.	165.251	9,3	382.525

The amounts of municipal waste from tourism were calculated using the "*Methodological work on measuring the sustainable development of tourism, Part 2: Manual on sustainable development indicators of tourism*", European Commission, 2006.

Table 7. The quantity of municipal waste from tourism per County in Croatia in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode)

County	Number of overnights stays	The quantity of municipal waste from tourism (t)	Portion of municipal waste from tourism produced in different County in total amount of produced municipal waste in tourism in Croatia (%)	Portion of municipal waste from tourism in total amount of produced municipal waste in different County (%)
1. Zagrebačka	245.976	197	0,12%	0,22%
2. Krapinsko-zagorska	418.139	262	0,16%	0,91%
3. Sisačko-moslavačka	144.439	121	0,07%	0,27%
4. Karlovačka	745.576	752	0,46%	1,72%
5. Varaždinska	203.980	133	0,08%	0,33%
6. Koprivničko-križevačka	52.402	43	0,03%	0,13%
7. Bjelovarsko-bilogorska	114.497	92	0,06%	0,29%
8. Primorsko-goranska	22.704.944	30.224	18,29%	17,96%
9. Ličko-senjska	3.966.506	5.059	3,06%	19,39%
10. Virovitičko-podravska	48.331	38	0,02%	0,18%
11. Požeško-slavonska	44.530	30	0,02%	0,18%
12. Brodsko-posavska	71.729	52	0,03%	0,14%
13. Zadarska	16.580.662	23.813	14,41%	21,27%
14. Osječko-baranjska	242.744	209	0,13%	0,24%
15. Šibensko-kninska	7.950.674	10.653	6,45%	17,86%
16. Vukovarsko-srijemska	169.927	155	0,09%	0,30%
17. Splitsko-dalmatinska	22.216.876	32.502	19,67%	11,96%
18. Istarska	33.939.916	43.681	26,43%	30,82%
19. Dubrovačko-neretvanska	10.313.608	13.400	8,11%	18,90%
20. Međimurska	227.764	186	0,11%	0,56%
21. Grad Zagreb	3.027.289	3.649	2,21%	1,02%
Total quantity:	**123.430.507**	**165.251**	**100,00%**	**9,34%**

Table 8. The quantity of municipial waste produced per County in Croatia in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode)

County	The quantity of municipal waste produced per County (t)	Portion of the quantity of municipal waste produced per County in municipal waste produced	Number of Inhabitants 2011 (DZS)	The quantity of municipal waste produced per capita (kg/inhabitant)
1. Zagrebačka	90.473	5%	317.606	285
2. Krapinsko-zagorska	28.921	2%	132.892	218
3. Sisačko-moslavačka	45.409	3%	172.439	263
4. Karlovačka	43.766	3%	128.899	340
5. Varaždinska	39.943	2%	175.951	227
6. Koprivničko-križevačka	32.421	2%	115.584	280
7. Bjelovarsko-bilogorska	31.707	2%	119.764	265

8. Primorsko-goranska	168.328	10%	296.195	568
9. Ličko-senjska	26.091	2%	50.927	512
10. Virovitičko-podravska	21.690	1%	84.836	256
11. Požeško-slavonska	16.946	1%	78.034	217
12. Brodsko-posavska	37.412	2%	158.575	236
13. Zadarska	111.962	7%	170.017	659
14. Osječko-baranjska	87.408	5%	305.032	287
15. Šibensko-kninska	59.633	3%	109.375	545
16. Vukovarsko-srijemska	51.415	3%	179.521	286
17. Splitsko-dalmatinska	271.764	15%	454.798	598
18. Istarska	141.751	8%	208.055	681
19. Dubrovačko-neretvanska	70.883	4%	122.568	578
20. Međimurska	32.896	2%	113.804	289
21. Grad Zagreb	357.591	19%	790.017	453
Total quantity:	1.768.411			432

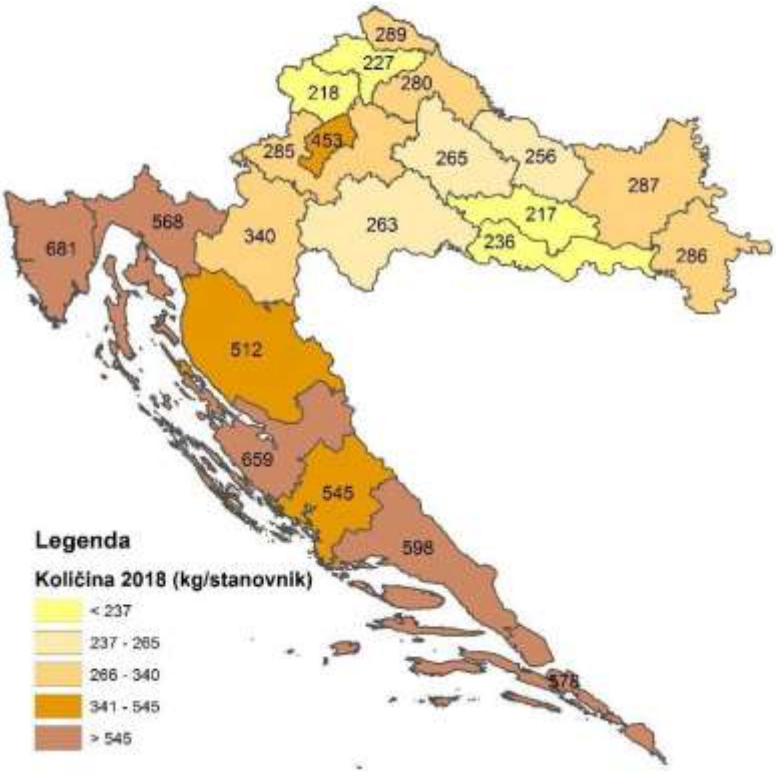


Figura 19. The quantity of municipal waste produced per County pro capite in Croatia in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode)

Besides the effects of tourism, the deviations from average quantities of waste that can be noted in some counties, municipalities and cities, can be caused additionally by not weighing the waste, which often results with subpar estimations of the quantities of waste received.

Table 9. The quantity of mixed and other types of municipal waste collected per County in 2018 (Source: Source: MZOE, Zavod za zaštitu okoliša i prirode)

County	Municipal waste generated (t)	Mixed municipal waste generated (20 03 01) (t)	Portion of mixed municipal waste in municipal waste generated per County (%)	Other types of municipal waste collected except the municipal waste number 20 03 01 (t)	Portion of other types of municipal waste collected in municipal waste collected per County (%)
1. Zagrebačka	74.037	54.935	74%	19.101	26%
2. Krapinsko-zagorska	23.575	18.549	79%	5.026	21%
3. Sisačko-moslavačka	36.821	33.370	91%	3.452	9%
4. Karlovačka	35.499	31.395	88%	4.104	12%
5. Varaždinska	33.419	20.537	61%	12.883	39%
6. Koprivničko-križevačka	26.291	17.819	68%	8.472	32%
7. Bjelovarsko-bilogorska	25.858	20.848	81%	5.010	19%
8. Primorsko-goranska	136.623	100.796	74%	35.827	26%
9. Ličko-senjska	21.203	20.020	94%	1.183	6%
10. Virovitičko-podravska	17.587	14.730	84%	2.857	16%
11. Požeško-slavonska	13.740	11.991	87%	1.749	13%
12. Brodsko-posavska	30.515	24.080	79%	6.435	21%
13. Zadarska	90.789	83.120	92%	7.669	8%
14. Osječko-baranjska	71.294	56.588	79%	14.706	21%
15. Šibensko-kninska	48.823	42.665	87%	6.158	13%
16. Vukovarsko-srijemska	41.847	38.138	91%	3.709	9%
17. Splitsko-	221.704	197.507	89%	24.196	11%
18. Istarska	114.937	90.107	78%	24.829	22%
19. Dubrovačko-neretvanska	57.478	48.804	85%	8.674	15%
20. Međimurska	26.682	13.889	52%	12.792	48%
21. Grad Zagreb	295.477	216.631	73%	78.845	27%
The quantity of mixed and other types of municipal waste collected per County in 2018.	1.444.197	1.156.521	80%	287.676	20%
Estimations:	324.214	58.099		266.115	
Total quantity:	1.768.411	1.214.620	69%	553.791	31%

Table 10. The quantity of separately collected municipal waste per County in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode).

County	Paper & cardboard (t)	Plastic (t)	Metal (t)	Glass (t)	Bulky waste (t)	Textiles (t)	Biodegradable waste (t)
1. Zagrebačka	3.511	3.348	177	834	5.405	425	593
2. Krapinsko-zagorska	919	1.473	59	231	1.257	208	86
3. Sisačko-moslavačka	1.070	378	32	265	1.195	53	180
4. Karlovačka	876	286	2	109	1.814	30	100
5. Varaždinska	2.525	1.045	119	647	942	259	1.055
6. Koprivničko-križevačka	1.100	882	130	349	1.386	127	3.440
7. Bjelovarsko-bilogorska	1.563	212	5	197	342	4	377
8. Primorsko-goranska	7.199	1.532	134	1.684	13.103	275	9.190
9. Ličko-senjska	381	49	4	114	169		213
10. Virovitičko-podravska	2.013	396	3	91	97	15	
11. Požeško-slavonska	963	140	4	233	248	32	103
12. Brodsko-posavska	1.146	154	40	251	1.415	17	2.422
13. Zadarska	1.545	623	57	68	3.593	19	1.669
14. Osječko-baranjska	4.528	1.719	28	278	910	47	4.899
15. Šibensko-kninska	605	84	34	24	2.614	3	161
16. Vukovarsko-srijemska	1.651	313	30	208	440	30	25
17. Splitsko-dalmatinska	3.002	189	117	345	10.755	3	0
18. Istarska	5.445	947	340	1.462	9.599	105	3.489
19. Dubrovačko-neretvanska	3.114	697	253	683	2.863	2	981
20. Međimurska	1.663	1.734	289	1.104	1.183	19	6.186
21. Grad Zagreb	10.072	3.540	220	2.305	22.150	864	1.583
Sakupljeno u organizaciji JLS:	54.891	19.742	2.076	11.480	81.478	2.537	36.752
Količine sakupljene putem trgovanja na malo i dodatno utvrđene količine:	126.96 6	21.499	31.451	41.176	19.925	151	33.272
Total quantity (t):	181.85	41.241	33.528	52.656	101.40	2.689	70.024

Table 11. The quantity of separately collected municipal waste in 2018. (Source: MZOE, Zavod za zaštitu okoliša i prirode)

Types of waste	Quantity (t)
Paper and cardboard	181.857
Bulky waste	101.403
Biodegradable waste	70.024
Glass	52.656
Plastic	41.241
EE Waste	38.072
Metal	33.528
Wood	11.708
Textile	2.689
Batteries and accumulators	104
Other	20.509
Total quantity (t):	553.791

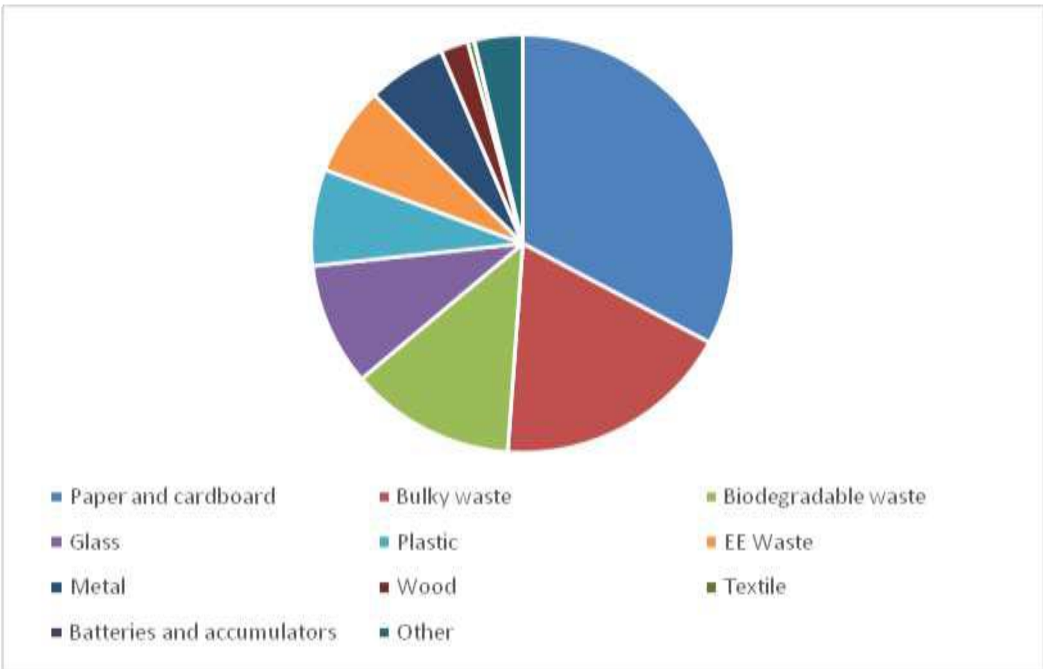


Figura 20. The quantity of separately collected municipal waste per County in 2018 (Source: MZOE, Zavod za zaštitu okoliša i prirode)

MZOE stated that an amount of 204.961 t of packaging was collected in 2018. which makes 37% of total quantity of separately collected municipal waste in 2018. Paper and cardboard waste makes the largest portion of separately collected municipal waste, 51%, while plastic makes 16%.

Table 12. Municipal waste management per county in Croatia in 2018. – municipal waste collected by different municipalities (Source: Source: sheets SO-1, SO3-1 and SO3-2, database ROO)

County	Quantity of municipal waste collected (t)	Municipal waste landfilled (t)	Portion of municipal waste landfilled (%)	Quantity of municipal waste recycled (t)	Portion of municipal waste recycled (%)	Other (t)
1. Zagrebačka	70.456	51.654	73,3%	12.538	17,8%	6.263
2. Krapinsko-zagorska	22.916	19.035	83,1%	3.457	15,1%	424
3. Sisačko-moslavačka	36.813	34.955	95,0%	1.847	5,0%	12
4. Karlovačka	35.437	34.056	96,1%	1.229	3,5%	152
5. Varaždinska	27.963	18.906	67,6%	6.969	24,9%	2.089
6. Koprivničko-križevačka	26.276	19.971	76,0%	5.405	20,6%	900
7. Bjelovarsko-bilogorska	25.070	22.959	91,6%	2.060	8,2%	51
8. Primorsko-goranska	135.903	44.201	32,5%	21.189	15,6%	70.513
9. Ličko-senjska	20.951	20.062	95,8%	430	2,1%	460
10. Virovitičko-podravska	17.587	15.035	85,5%	2.226	12,7%	326
11. Požeško-slavonska	13.740	12.282	89,4%	1.414	10,3%	45
12. Brodsko-posavska	29.564	27.908	94,4%	1.639	5,5%	16
13. Zadarska	90.760	88.338	97,3%	2.136	2,4%	286
14. Osječko-baranjska	69.071	57.622	83,4%	11.412	16,5%	36
15. Šibensko-kninska	46.339	45.279	97,7%	622	1,3%	438
16. Vukovarsko-srijemska	41.014	38.627	94,2%	2.239	5,5%	148
17. Splitsko-dalmatinska	214.581	209.370	97,6%	5.198	2,4%	13
18. Istarska	114.937	62.339	54,2%	10.795	9,4%	41.803
19. Dubrovačko-neretvanska27	57.463	49.828	86,7%	6.943	12,1%	691
20. Međimurska	26.639	14.449	54,2%	11.549	43,4%	641
21. Grad Zagreb	266.251	216.631	81,4%	49.543	18,6%	76
Total quantity	1.389.728	1.103.508	79,4%	160.839	11,6%	125.381

3 Annotated Bibliography

Introduction and Current status of plastics cycle bibliography

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Synthesis

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Synthesis

This review shows that energy conversion technologies such as incineration, pyrolysis, gasification, anaerobic digestion, ethanol fermentation, landfill and future trends like microbial fuel cell (MFC) and microbial electrolysis cell (MEC) are the main ways for waste to energy (WtE) conversion. Among those WtE technologies are ecologically green that convert MSW into electricity, hydrogen gas and other chemical feedstocks. The review suggests that MFC and MEC technologies forecast future WtE for fabrication of biohydrogen from MSW.

Biancolini V., Canè M., Fornaciari S., Forti S. (2011) Le emissioni degli inceneritori di ultima generazione, Quaderni di Moniter, 03-11.

Synthesis

Latest generation incinerator emission report. Analysis of the Frullo plant in Bologna.

EC (2000). Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.

Synthesis

The purpose of this Directive is to prevent or to limit as far as practicable negative effects on the environment, in particular pollution by emissions into air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste.

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Synthesis

EPA summary on the Sustainable Materials Management.

European Commission. (2018). A European Strategy for Plastics. European Comission, (July), 24. https://doi.org/10.1021/acs.est.7b02368

Synthesis

This is the first European Strategy for Plastics in a Circular Economy adopted on January 2018, will transform the way plastic products are designed, used, produced and recycled in the EU. Better design of plastic products, higher plastic waste recycling rates, more and better quality recyclates will help boosting the market for recycled plastics. It will deliver greater added value for a more competitive, resilient plastics industry.

Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials, 344, 179–199. https://doi.org/10.1016/j.jhazmat.2017.10.014

Synthesis

The present overview highlights the waste management and pollution challenges, emphasizing on the various chemical substances (known as “additives”) contained in all plastic products for enhancing polymer properties and prolonging their life. Despite how useful these additives are in the functionality of polymer products, their potential to contaminate soil, air, water and food is widely documented in literature and described herein. These additives can potentially migrate and undesirably lead to human exposure via e.g. food contact materials, such as packaging. They can, also, be released from plastics during the various recycling and recovery processes and from the products produced from recyclates. Thus, sound recycling has to be performed in such a way as to ensure that emission of substances of high concern and contamination of recycled products is avoided, ensuring environmental and human health protection, at all times.

ISPRA (2017) Rapporto Rifiuti Urbani, Report 272/2017

Synthesis

Report prepared by the National Waste Cycle Center of the Higher Institute for Environmental Protection and Research (ISPRA) concerning the state of waste in the European Union.

Kotiba H., Mosab K., Fawaz D. (2013) Recycling of waste from polymer materials: An overview of the recent works. Polymer Degradation and Stability 98, 2801-2812.

Synthesis

This paper reviews the recent progress on recycling of polymeric waste form some traditional polymers and their systems (blends and composites) such as polyethylene (PE), polypropylene (PP), and polystyrene (PS), and introduces the mechanical and chemical recycling concepts. In addition, the effect of mechanical recycling on properties including the mechanical, thermal, rheological and processing properties of the recycled materials is highlighted in the present paper.

PlasticsEurope. (2018). Plastics – the Facts. Plastics – the Facts 2018, 38. Retrieved from https://www.plasticseurope.org/it/resources/publications/619-plastics-facts-2018

Synthesis

The data presented in this report was collected by PlasticsEurope (the Association of Plastics Manufacturers in Europe) and EPRO (the European Association of Plastics Recycling and Recovery Organisations). PlasticsEurope's Market Research and Statistics Group (PEMRG) provided input on the production and the demand of plastic raw materials. Conversion Market & Strategy GmbH helped assess waste collection and recovery data. Official statistics from European or national authorities and waste management organizations have been used for recovery and trade data, where available.

Presidenza del Consiglio dei Ministri. Sea safe bill (Legge Salvamare) 2 Aprile 2019.

Synthesis

"Salvamare" bill: The fishermen will be able to bring the accidentally finished plastic into the nets without penalties.

Scalenghe, R. (2018). Resource or waste? A perspective of plastics degradation in soil with a focus on end-of-life options. Heliyon, 4(12), e00941. https://doi.org/10.1016/j.heliyon.2018.e00941

Synthesis

This review collects existing information on plastics in the soil, paying particular attention to both their degradation and possible re-uses. The use of plastics in agriculture is also considered. The discussion is organised according to their resin type and the identification codes used in recycling programs. In addition, options for post-consumer plastics are considered. Acknowledged indicators do not exist, and future study they will have to identify viable and shared methods to measure the presence and the degradation of individual polymers in soils.

Science Communication Unit. (2011). Plastic Waste: Ecological and Human Health Impacts. In Science for Environment Policy. https://doi.org/KH-31-13-768-EN-N

Synthesis

This report deals with plastic waste: key factors and pressures, the state of plastic waste in the environment and impacts on the health of ecosystems.

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Synthesis

This paper compiles the different research work done by researchers in this field of recycling and progress in recovery and management of PSW by different methods (i.e. Primary, secondary, tertiary and quaternary) along with the various identification/separation techniques. Further, this paper reviews the effect on properties of virgin and recycled HDPE/LDPE/Nylon PSW with different reinforcements like sand, natural fibre, hemp fibre, metal powder etc.

The Italian and Croatian situation bibliography

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