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System innovation and life cycle thinking in packaging value chain: the circularity of plastics.

Presentata da: **Eleonora Foschi**

Coordinatore Dottorato
Prof. Luca Vittuari

Supervisore
Prof.ssa Alessandra Bonoli

Co-supervisore
Prof. Francesco Di Maio

Esame finale anno 2020

“To see far is one thing, going there is another.”

“Think globally, act locally.”

DECLARATION

The present thesis is the result of my individual effort and work. The research has been carried out during the three-years PhD programme at the *Department of Civil, Chemical, Environmental and Materials Engineering – University of Bologna* (Italy). An important contribution has been realized during the research period abroad at the *Delft University of Technology* (Netherlands), working with the Resource and Recycling research group.

This full dissertation has not been formerly submitted to the public, except of specific parts which have been submitted to specific journals (*Journal of Cleaner Production, Journal of Administrative Science, Journal of Environmental Science & Pollution Research*) or reports as outcomes of European projects (*Roveri Smart Village, eCircular- Catalysing a switch to a circular economy through plastic waste prevention, CEI - Circular economy for plastic value chain in manufacturing, TRIS - Transition regions towards industrial symbiosis*) and initiatives (*ICESP - Italian Circular Economy Stakeholder Platform, SUN - Symbiosis User Network*) in which I have been involved. References made to other scientific works or sources have been duly cited and acknowledged.

ABSTRACT

Compared to other, plastic materials have registered a strong acceleration in production and consumption during the last years. Despite the existence of waste management systems, plastic_based materials are still a pervasive presence in the environment, with negative consequences on marine ecosystem and human health. The recycling is still challenging due to the growing complexity of product design, the so-called overpackaging, the insufficient and inadequate recycling infrastructure, the weak market of recycled plastics and the high cost of waste treatment and disposal. The *Circular economy package*, the *European Strategy for plastics in a circular economy* and the recent *European Green Deal* (that contains the *New Action plan on Circular Economy)* include very ambitious programmes to rethink the entire plastic value chain. The mission of the Commission is to highlight the intrinsic value of materials along the value chain and in further cycles. As regards packaging, all plastic packaging will have to be 100% recyclable (or reusable) and 55% recycled by 2030. Regions are consequently called upon to set up a robust plan able to fit the European objectives. It takes on greater importance in Emilia Romagna where the *Packaging valley* is located. This thesis supports the definition of a strategy aimed to establish an after-use plastics economy in the region. The PhD work has set the basis and the instruments to establish the so-called *Circularity Strategy* with the aim to turn about 92.000t of plastic waste into profitable secondary resources. System innovation, life cycle thinking and participative backcasting method have allowed to deeply analyse the current system, orientate the problem and explore sustainable solutions through a broad stakeholder participation. A material flow analysis, accompanied by a barrier analysis, has supported the identification of the gaps between the present situation and the 2030 scenario. The study has pointed out the necessity to reduce waste at first, increase the quality of collection then and finally, deal with the problem of the plasmix Eco-design for and from recycling (and a mass _based recycling rate (based on the effective amount of plastic wastes turned into secondary plastics), valorized by a value_based indicator, are the key-points of the action plan. The eco-design tool will support the plastic packaging manufacturers to improve the recycling performance at the end-of-life. At the same time, the structure of the tool (organized as a check list) will support the identification of the number of recyclable packaging placed on the market. The framework of indicators will be used to assess how much value the recyclers are able to extract from waste. Their monitoring will speed up the market of secondary plastics in the direction of high value applications, thus effectively contributing to reduce the supply of virgin plastics. The model, at the basis of the regional strategy, may be exported in other regions thus promoting standardization in design, harmonization in the assessment of recycling performance as well as the introduction of a reliable and robust circular economy indicator by which increase competitiveness and foster the after-use plastics economy in local scale thus reducing export, illegal trade and arson.

Key words: System Innovation, Backcasting method, Plastics, Packaging, Waste Management System, Circularity.

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ABBREVIATIONS AND ACRONYMS

A&I Active and Intelligent

ABS Acrylonitrile-Butadiene-Styrene

AMI Applied Market Information

ANCI National Association of Italian municipalities

APME

APR Association of Plastic Recyclers

ARPAE Regional Agency for Prevention, Environment and Energy of Emilia-Romagna

AT Austria

BAT Best Available Techniques

BAU Business as Usual

B&C Building and construction

BE Belgium

BFR Brominated Flame Retardants

BG Bulgaria

BMI Maleimide/bismaleimide

BO Bologna

BPA Bisfenol A

BPF British Plastics Federation

BREF BAT Reference Documents

BtB Business to Business

BtC Business to Consumer

CA Cellulose Acetate

CAC ANCI-CONAI Contribution

CAM Minimum Environmental Criteria

CC Pre-sorting plant (associated to COREPLA)

CE Circular Economy

CEIP Circular Economy Indicator Prototype

CET Circular Economy Toolkit

CFC Chlorofluorocarbon

CH Switzerland

CIC National Consortium of Composting Plants

CLP Classification, labelling and packaging

CO Carbon oxide

CO_2 Carbon dioxide

CONAI National Packaging Consortium

CONIP National Independent Plastic Packaging Consortium

COREPLA National Consortium for the Collection and Recycling of Plastic packages

CORIPET National Independent Consortium for PET bottles

CLR Closed-loop Recycling

CNA National Confederation for Craft and Small-Medium-Enterprises

CIR Food National Cooperative Society for Restoration/Catering

CPR Collective Producer Responsibility

CSA Chemical Safety Assessment

CSR Sorting and Recycling plant (associated to COREPLA)
CSS Sorting plant (associated to COREPLA)
CVORR Complex Value Optimisation for Resource Recovery
CY Cyprus
CZ Czech Republic
DE Germany
DfE Design for Environment
DfM Design for Manufacturing
DforR Design for Recycling
DfromR Design from Recycling
DfRem Design for Remanufacturing
DfX Design for X
DG Directorate General
DG EC, ERR Directorate General of Economy, Emilia Romagna Region
DG ENV, ERR Directorate General of Environment, Emilia Romagna Region
DG RIN, MinAmb Directorate General of Waste and pollution, Ministry of Environment
DK Denmark
DMC Direct Material Consumption
DRS Deposit Return Scheme
EAP East Asia and Pacific
EC European Commission
ECHA European Chemicals Agency
EE Estonia
EEA European Environment Agency
EEB European Environmental Bureau
EE Electrical-electronic
EFSA European Food Safety Authority
EFT Foreign Trade Statistics
EKC Economic Kuznet Curve
ENEA National Agency for New Technologies, Energy and Sustainable Economic Development
EoL End-of-life
EPBP European PET Bottle Platform
EPOXY Polyepoxide
EPR Extended Producer Responsibility
EPS Expanded Polystyrene
ERR Emilia Romagna Region
ERVET Consortium for innovation and technology transfer of Emilia-Romagna region (actually ART-ER)
ES Spain
EU European
EU-28 European Union of 28 Member States
EuPC European Plastics Converters
EUPIA European Printing Ink Association
EUROMAP European Plastics and Rubber Machinery
EUROPEN European Organization for Packaging and the Environment
EWC European Waste Classification

EWD Waste Framework Directive

EXPRA Extender Producer Responsibility Association

FC Forlì-Cesena

FCM Food Contact Material

FE Ferrara

FI Finland

FMCG Fast moving consumer good

FPE Flexible Packaging Europe

FR France

GB Great Britain

GDP Gross domestic products

GHG Greenhouse gas

GPP Green Public Procurement

GR Greece

GWP Global warming potential

HDPE High-density polyethylene

HIPS High impact polystyrene

HU Hungary

IE Ireland

IED Industrial Emission Directive

IPR Individual Producer Responsibility

IPP Mixed PP packaging

ISO International Organization for Standardization

ISPRA Italian Institute for Environmental Protection and Research

IT Italy

KC Kuznet curve

KPI Key-performance-indicator

Kt Kiloton

LCA Life Cycle Assessment

LCT Life Cycle Thinking

LDPE Low-density Polyethylene

LEAP-POLIMI Energy and Environment Lab Piacenza

LLDPE Linear low-density polyethylene

LT Lithuania

LT Long-Term

LV Latvia

LU Luxembourg

MAP Modified Atmosphere Packaging

MBI Market-based Instrument

MBT Mechanical-biological treatment

MCI Material Circularity Index

MDI Methylenediphenyl diisocyanate

MF Melamine formaldehyde

MFF Multiannual Financial Framework

MFA Material Flow Analysis

MLP Multi-Level-Perspective
MO Modena
MORE Monitoring Recyclates for Europe
MPP Marine Plastic Pollution
MRF Material Recovery Facilities
MS Member State
MT Malta
MT Medium-term
Mt Million metric tonne
MUD Environmental Declaration Form
NACE Statistical Classification Of Economic Activities In The European Community
NIR Near infra-red rays
NL Netherlands
NO Norway
NGO Not-profit organization
OECD Organisation for Economic Co-operation and Development
ORSo Inter-regional Waste Observatory
PA Polyamide (Nylon)
PARI Independent consortium for LDPE Flexible Packaging
PAYT Pay As You Throw
PBAT Polybutylene Adipate Terephthalate
PBB Polybrominated Biphenyls
PBT Polybutylene Terephthalate
PC Piacenza
PC Polycarbonate
PCPPW Post-consumer Plastic Packaging Waste
PCR Post-consumer recycled
PC/ABS Polycarbonate/Acrylonitrile Butadiene Styrene
PBB Polybrominated Biphenyl
PBDE Polybrominated Diphenyl Ether
PBS Polybutylene Succinate
PE Polyethylene
PE/ABS Polyethylene/Acrylonitrile Butadiene Styrene
PEEK Polyetheretherketone
PEPS - Platform for PS packaging
PES Polyester
PESTEL Political, economic, social, technological, environmental, legal
PET Polyethylene Terephthalate
PF Phenolics or Phenol Formaldehyde
PHA Polyhydroxy Alkenoate
PIA - Platforms for General Industrial Packaging Management
PIFU - Platforms for Drums and Tanks
PL Poland
PLA Polylactic acid
PMMA Polymethyl Methacrylate

PO Polyolefin

POP Persistent Organic Pollutant

PoTS Potentially Toxic Substance

PP Polypropylene

PPW Plastic Packaging Waste

PPWD Packaging and Packaging Waste Directive

PR Parma

PRO Packaging Recovery Organisation

PRE PlasticsRecyclersEurope

PS Polystyrene

PT Portugal

PTFE Polytetrafluoroethylene

PU/PUR Polyurethane

PVC Polyvinyl Chloride

PVDC Polyvinylidene Chloride

REACH Registration, Evaluation, Authorisation and Restriction of Chemicals

RA Ravenna

RE Reggio Emilia

rHDPE Recycled HDPE

rLDPE Recycled LDPE

RN Rimini

rPET Recycled PET

RO Romania

R&D Research & Development

SRA Secondary Reducing Agent

RWMS Regional Waste Management Plan

SA Stakeholder analysis

SE Sweden

SELE-CAS/M Plastic crate

SELE-CTA/M Light blue PET bottle

SELE-CTC/F Mixed PET bottle

SELE-CTC/M Coloured PET bottle

SELE-CTE/M HDPE Rigid container

SELE-CTL/F Clear PET bottle

SELE-CTL/M Transparent PET bottle

SELE-FIL/M Film packaging

SELE-FILM/C Packaging film

SELE-FIL/S Small/sized film

SELE-IPP/C Mixed PP packaging

SELE-MPET/C Mixed coloured flexible packaging

SELE-MPO/B

SELE-MPO/C Mix of rigid PO packaging

SELE-MPOF/C Mix of flexible PO packaging

SELE-MPR/C Rigid PO containers

SELE-MPR/S

SELE-PET/C Opaque PET bottle

SELE-PLASMIX/R Plasmix

SELE-VPET PET trays

SI Slovenia

SK Slovakia

S.N.C. General Partnership

SOC. COOP. Cooperative Society

SP Secondary Plastic

S.P.A. Public Limited Company

SPI Society of the Plastics Industry

S.R.L. Limited Liability Company

ST Short-term

SUP Single-use plastic

SVCH Substance Of Very High Concern

SWOT Strengths, Weaknesses, Opportunities, and Threats

t Tonne

TEU Total Energy Use

UCIMA National Association of Packaging Machinery Manufacturers

UNEP United Nations Environment Programme

UF Urea-formaldehyde

UNIBO University of Bologna

UK United Kingdom

US United States

US EPA United States Environment Protection Agency

USD United States dollar

VAT Value Added Tax

VPvB Very Persistent And Very Bio-accumulative

WCED

WKC Waste Kuznet Curve

WMS Waste Management System

WP Waste Prevention

WtE Waste-to-energy

EXECUTIVE SUMMARY

Problem statement: plastics, from resource to problem

Plastics are highly durable non-biodegradable materials made from petroleum products (Landon-Lane, 2018; Eagle et al., 2016), with a lifespan ranging from hundreds to thousands of years (Wang et al., 2016). The impressive success of plastics is unparalleled by any competing materials (Lebreton and Andrady, 2019). Their versatile nature and durability make them indispensable, prompting its high demand and use globally. Plastic materials have registered an exponential growth over the past half-century, accounting for 1,7 million metric tonnes (Mt) produced in 1950 to 15Mt in 1964 up to 359Mt in 2018 ((Kwon et al., 2018; PlasticsEurope, 2019, Ellen MacArthur Foundation, 2016, Karlsson et al., 2018; Napper et al., 2015; Jambeck et al., 2015). This is partially caused by the replacement of steel in cars, glass and paperboard in packaging, cotton in clothes and wood in furniture (Le Blevennec et al., 2019). The change in living standards can be considered an additional factor contributing to the raise of plastics production and consumption. In particular, the "on the go" life style (WPO, 2008) is strongly affecting the consumption of the so-called fast moving consumer goods (FMCGs) (Crippa et al., 2019) that stands at 98 billion articles and about 8.5Mt of packaging respectively sold and consumed annually (Villanueva and Eder,2014). This means that the majority of plastics produced each year is used to make disposable items that are immediately discarded (Hopewell et al., 2009). The waste management infrastructure is not adequate to receive and treat the current amount of plastic waste generated in Europe so as to be still widely underperforming (Foschi and Bonoli, 2019). The increasing complexity on design, the lack of recycling facilities capacity and the weak market of secondary plastics (SPs) have been contributing to the inefficiency and mismanagement of End-Of-Life (EoL) of plastic goods (Gallimore and Cheung, 2016; Velis and Brunner, et al., 2013). Consequently, more and more plastic wastes have been exported to EAP (East Asia and Pacific) countries (Geyer et al., 2017). Europe is the major exporter of plastic waste accounting for 37% of global waste exports. China is the main destination: the amount of plastic waste sent from Europe to China accounts for 1,6Mt in 2016. China receives waste from the entire globe getting a cumulative 45% of plastic waste since 1992 (amounting to around 106Mt). As a consequence, China implemented a new policy banning the importation of most plastic waste (Brooks et al., 2018). Waste that are no longer exported to EAP countries, are exported to other Eastern countries such as Vietnam, Malaysia, Hong Kong and Turkey (EUROSTAT). Since the remaining amount cannot be incinerated because of the increasing costs, it is piled up in storage sites causing uncontrolled burning or illegal braze. The fragmentation in responsibilities and the inability of accurate traceability in global waste shipment has caused widespread problems (Eagle et al, 2016). For example, the threat of plastics to the marine environment has been ignored for a long time. Because of the critical level reached by the dispersion and the accumulation of mismanaged plastic waste in marine environment, its seriousness has been only recently recognised (Stefatos et al., 1999; Lebreton and Andrady, 2019; Imogen et al., 2019). It is supposed that the leakage is more acute where waste management infrastructure is less developed. However, in addition to sea-based sources, a certain amount of plastic wastes ends up in the marine environment when accidentally lost and carelessly handled (Wilber, 1987). Many studies demonstrated that the major inputs of plastic litter come from land-based sources in densely populated or industrialized areas (Pruter, 1987; Gregory, 1991), most in the form of packaging. In fact, the short shelf life and consequently, the inappropriate value given to packaging, has significantly increased the urban littering (Liu and Sibley, 2004, Passafaro et al., 2015). Owing to the low degradability, especially in aquatic habitats (Andrady, 2003), plastic packaging remain in the environment for range from decades to centuries (Browne et al., 2007) to the extent that many commercial packets and wrappers, put into the market more than 50 years ago, are recovered in the whole world shores, seas and seabed (Jambeck et al., 2015). The low degradability of plastics in the short period has raised many public health issues, particularly referred to the eco-toxicological impacts of micro and nano plastics in food chain (Lusher et al., 2017). Therefore, the plastic sector is likely to undergo radical changes over the next two decades in order to speed up the transition toward more sustainable and circular production and consumption patterns.

Challenge: a systemic paradigm to foster an-after use plastic economy

The plastic value chain is faced multiple challenges to make more sustainable production and consumption patterns. As aforementioned, many critical issues affect the plastics recycling and re-manufacturing. Closed-loop recycling is most practical when recyclability is taken into account in the design phase. United Nations Environment Programme’s (UNEP) (2015) opinion about sustainable production and consumption patterns is about consuming efficiently to improve the quality of life while minimizing waste and environmental damage (Jackson, 2005). Circular economy (CE) plays a primary role in fostering the rethinking of plastics towards a more sustainable system, going well beyond resource efficiency and waste recycling. CE models promote not only the circularity of materials, but also the reduction of materials. The goal is maintaining the value as long as possible in a circle. The circularity of a product is thus determined not only by the intrinsic product characteristics, but also by the system of which it is a part (European Environmental Agency, 2017). Some pathways to reduce plastic waste are currently investigated: replacement of fossil-based plastics by bio-based materials, eco-designing, sustainable plastics manufacturing advancement, awareness enhancing, waste management improving and cleaning activities scattering. When a product is designed, preventive measures such as product_service system, light-weighting and all the actions aimed to extend the product lifespan support the reduction of the waste and prior, of primary resources. In fact, preventing resource at first and waste then, largely contribute to minimize the environmental impact. Recycling, in coordination with actions aimed to improve its performance by the design, should be taken into consideration for products that cannot be dematerialized.

Preventive measures as well as recycling need the integration of economic, technological and environmental aspects thus requiring inter and trans-disciplinary cooperation of all the stakeholders working in the plastic value chain. It follows that collaboration should also be transversal thus involving economists, social science experts and policy and decision makers in each step of the value chain. Only by bringing together relevant stakeholders to discuss common problems and possible strategies, efficient measures may emerge (Hagemeir et al., 2014). By approaching the problem from different perspectives, a stronger action is enforced. Therefore, a systemic rethinking of production, consumption and disposal patterns is crucial to overcome the limitations of today's incremental improvements and fragmented initiatives. The systemic thinking also helps to create a shared sense of direction and to move the plastics value chain into a model characterized by value capture, stronger economics, and better environmental outcomes. As discussed by Vieira (1992), the systemic paradigm implies the integration of human ecology in environmental policy, which is guided by preventive rather than remedial view. Innovation is here considered as a transformation which takes place at the wider societal context, covering not only product and process innovations but also changes in user practices, markets, policy, regulations, culture, infrastructure, lifestyle, and management of firms (Berkhout, 2002; Geels, 2006; Kemp and Rotmans, 2005; Sartorius, 2006). It follows that establishing a sustainable plastics value chain needs the collaboration and cooperation of all the stakeholders working in design, manufacturing, distribution and waste management. This concept is extremely important in closed-loop system in which materials circulate as longer as possible in the circle (Geissdoerfer et al., 2017, Yuan and Moriguichi, 2008).

The European commitment towards a circular plastic economy

The redesign of the plastic_based materials system is one of the major issues discussed by the European Commission (EC) nowadays. EC has highlighted plastics as strategic materials in *Closing the loop Action Plan for the Circular Economy* (European Commission, 2015). Plastic materials have subsequently become the key topic in the *European Strategy for plastics in a circular economy* (European Commission, 2018). Specific measures have also included in the road map of the *European Green Deal* (European Commission, 2019a).

CE is actually seen in close synergy with sustainability aimed to fulfil a broader framework of environmental, social and economic concerns thus embracing one of the major issue at the turn of the century that is how to achieve sustainable development in which present generations fulfil their needs in such a way that future generations can meet their needs as well (WCED, 1987).

Even if EC holds the rein of the situation, a growing number of international agreements, national measures and business initiatives are trying to tackle the plastic waste problem (ten Brink et al., 2018). The industrial environment has been implementing an active behaviour by launching numerous initiatives such as alliance, joint-venture and more general collaboration. Many targets have been fixed as well. Just to mention some examples, the main plastic converters have joined the *Circular Plastic Alliance* to foster well-functioning market of recycled plastics. The *Alliance to End of Plastic Waste* has been committed by the main plastic producers with the aim to dedicate a combined total of $1 billion over the next five years to develop and scale solutions to minimize and manage plastic waste. Other expression of the high effort of plastic responsible industries is the diffusion of inter-firm alliances, recognized by Hagedoorn (2002) as an important organization form of innovative activities able to lead to a new view of industry structure. In addition to inter-firm alliances, industrial networking is pursued by technology-based joint ventures (Metcalfe and Coombs 2000), basically aimed to reinforce experimentation on bio plastics and recycled plastic applications. Among civil community, many plastic free initiatives have globally widespread. Nor are there lacking cases of alliance to recover plastic from the most critical area of the globe. The recent *Fair Plastic Alliance* is a valid example of sustainable model based on the integration of environmental and social issues by strengthening waste collection networks in developing countries (Foschi and Bonoli, 2019).

Method and approach: A forward-backword process to implement the circularity strategy

In a Business as usual (BaU) model, forecast predicts that the annual plastic production will increase by a third by 2015 and related carbon emissions could rise up to 233Mt carbon dioxide (CO_2) in 2050. Circular strategies may contribute to a reduction of nearly 50% in associated carbon emissions in Europe by 2050 (OECD, 2018). Many targets and goals have been set for 2030. In order to achieve these targets, a clear vision and a robust strategy are necessary. In order to do that, CE should penetrate in each step of the plastic value chain thus contributing to boost a system innovation. A comprehensive analysis of the present situation allows to understand the gap between the present and the envisioned future (Quist, 2016). This purpose is supported by the backcasting method application. Backcasting looks backwards from that future to the present in order to strategize and to plan how it could be achieved (Quist and Vergragt, 2006). The present analysis is aimed do identify contemporary structures blocking the changes towards a more circular plastic packaging system. Backcasting allows to define a robust strategy encompassing fragmented actions. It is particularly useful for policy analysis and policy development, but especially from a governmental perspective (Robinson, 1990). In this work, back casting methodology has been applied to set up the strategy to foster the transforming normative scenario about having an after-use plastics economy. That goal is promoted by the targets established by the EC on recyclability and recycling of plastic packaging by 2030. Potential recycling and recyclability of plastic packaging has been deeply investigated to overcome critical issues regarding the low value of plastics reprocessing, the low income of secondary market and therefore the low diffusion of an after-use plastics economy. It involves not only technical and technological aspects but also legislative ones; economic and social factors have also considered to create an impact not only at product level but also at systemic level. These aspects have required a deep knowledge on the plastic materials, plastic applications, plastic characterization in packaging sector and an extensive investigation on the value chain: from design to manufacturing and EoL.

Case study: Regional plastic packaging system

In order to fit the goals, the context specifications help to be more pragmatic. The regional system, governance and structure have been identified as case study. Since each EU Member State (MS) have to transpose the European (EU) Directives in two years, an incisive maneuver is essential to push the regional plastic economy towards sustainability and circularity. It takes on greater importance in Emilia Romagna where the *Packaging valley* is located. The packaging sector includes packaging and packaging machinery manufacturing with a contribution of 61,1% to the total turnover (Bentivogli et al., 2018). However, most of the companies working in the packaging district are small and medium. It follows that regional policy makers must implement activities able to support the sector in shifting their businesses. According to the system innovation, the present work aims to improve the packaging design as well as the system in which packaging works. The recent EU report *A circular economy for plastics* (European Commission, 2019b) explains that product design requires that stakeholders co-operate, bring together knowledge and share the responsibility for creating a circular system. Only a better communication and cross-cutting collaboration can support a more consciously redesign of plastic packaging. In this work, the participative backcasting method has allowed to engage regional plastics converters and recyclers together with researchers and policy and decision makers with the aim to understand the needs at first and try the solutions then. After a deeper understanding of the present situation (carried out through surveys, questionnaires, interviews, workshops and data analysis), problems have been strategically oriented to find solutions that have been explored from the socio-technical innovation viewpoint. It has been done by starting from micro to meso and macro level analysis, obtaining a multi-level perspective (MLP) understanding. As aforementioned, system thinking requires longitudinal and transversal observations. It follows that the MLP analysis have included social, economic, environmental and technical-technological issues. This considerable work is the basis of the Circularity strategy set up. The strategy aims to transpose EU goals in regional ones with the aim to increase the amount of recycled plastics to valorize in high value applications. The strategy wants also to support the regional policymakers to implement the regional plastics strategy *#PlasticFreER* (Regione Emilia Romagna, 2019). It is extremely important considering that only 62.319t (22%) are actually recycled and additional 91.581t should be recycled by 2030. Recyclability, recycling and circularity of plastic packaging are the key points of the strategy. Design (for and from recycling) and high value recycling have been identified as the supporting elements. While design is a measure fostering the product sustainability, recycling involves the process dimension. Since chemical recycling is not well-established nowadays, only mechanical processes are here considered.

Key findings: Life cycle technique to close the loop, from recyclability to circularity of plastic packaging

The approach here adopted goes beyond focusing on the manufacturing stage of a product and embraces the whole life cycle in a Life cycle Thinking (LCT) approach. In system innovation, LCT is not just a way to examine environmental impacts affecting the life of the product, but also a way to comprehend a broader set of upstream and downstream consequences of decisions in strategy planning and implementation (Thbrew et al., 2009). The three key-points of the Circularity strategy are modulated by designing the content of an apparatus that is intended to have a supporting function in improving recyclability in one side and recycling (and circularity) in another. The first must be undertaken by converters and the second and third elements are the concerns of recyclers and give valuable information in decision-making processes. Since the value of SPs is affected not only by design but also the recycling infrastructure, the recycling rate have been considered. As highlighted by the European Commission in the Green Deal (2019), "*Where waste cannot be avoided, its economic value must be recovered and its impact on the environment and on climate change avoided or minimised*", economic value assumes a great importance. The closure of the loop is estimated through value_based circularity indicator aimed to push high quality of post-consumer recycled (PCR) resource. The increase in value will boost the upcycling and in particular the use of recycled plastics in high-value applications such as the packaging application. The growing demand of SPs in packaging applications will foster the after-use plastics economy.

Future exploitation: from regional to European dimension

Since European measures and target must be contextualized in local economy, the work laid down on a common knowledge and different tools that represent the ways to reach the objectives, as shared among all the MSs. It means that European and local eco-design guidelines are matched and integrated to local governance and existing economic incentives and available market-based instruments (MBIs). Moreover, the interaction with local stakeholders has allowed to catch additional local barriers, challenges and needs. The establishment of a unique method to calculate the recycling yield will allow to monitor the local performance and permit the comparison among MSs. It will also support the calculation of the value_based indicator. It means that local strategy may be modulated for the national and EU dimensions. Even if the present thesis work focused the attention on the regional context, the following activity will aim to explore the possibility to standardize design requirements and circularity metrics of plastic packaging, thus promoting recyclability in one side and upcycling in another at EU level. Recyclability and remanufacturing of SPs in high value applications are the basis of an after-use plastic economy, both regional and EU. Its diffusion will support the reaching of the long-term (LT) objectives laid down by the Commission.

1 INTRODUCTION: SYSTEM INNOVATION IN PLASTIC PACKAGING

1.1 Region innovation

As we know, innovation is at the core of interest because the capability of generating new products and technologies is historically recognized as the key success factor for competitiveness of firms, regions and entire nations (Moulaert And Sekia, 2003; Asheim And Gertler, 2009; Mokyr, 1990).

Emilia Romagna is the spatial frame of this experimentation.

→ The Emilia Romagna is one of the most proficient Italian regions, located in the Northern area with a territory of 22.123 square kilometres and 4,5 million inhabitants with an average Gross domestic products (GDP) per capita of 35.3KEUR (one of the highest in Italy) and a total GDP of about 154 billion EUR in 2016 (ISTAT[1]).. It comprises 331 cities and 6 provinces ((Ferrara, Forlì-Cesena, Modena, Parma, Piacenza, Ravenna, Reggio Emilia and Rimini). The economic system is mainly feed by the manufacturing sector, including 43.000 companies and 480.000 jobs (UNIONCAMERE 2019).
According to the EU Innovation Scoreboard[2] (See Figure 1), the region is a moderate innovator with a n innovation index of 84,94 (European Commission, 2019c).

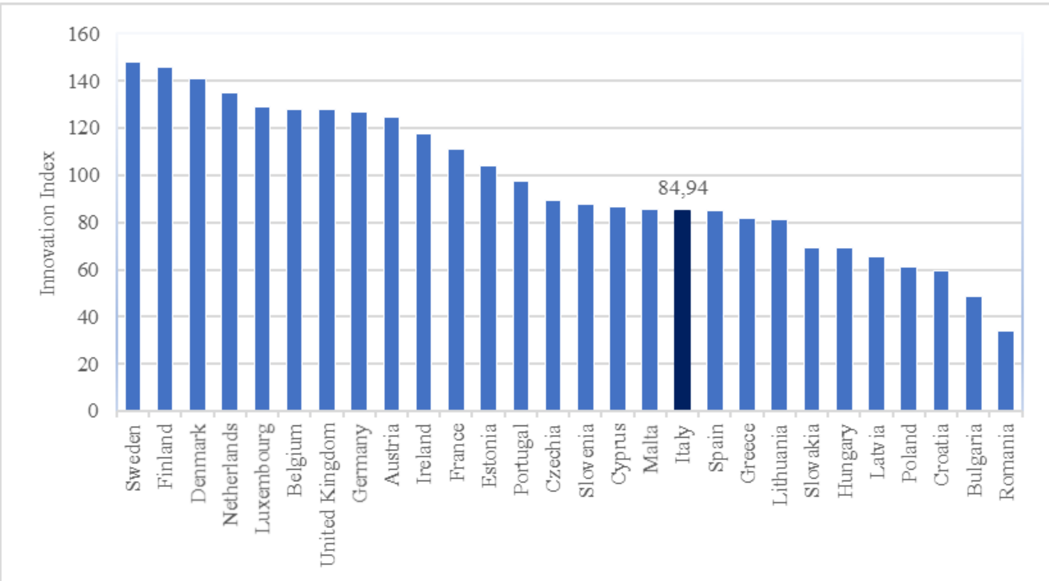


Fig. 1 Innovation Index in Europe, 2019 – Source: European Commission[3], 2019c

The following regional innovation scoreboard (See Figure 2), shows as the manufacturing industry has a pivotal role in fostering regional innovation.

[1] Source: ISTAT - https://www.istat.it/it/archivio/regioni
[2] The regional innovation scoreboard is a regional extension of the European innovation scoreboard, assessing the innovation performance of European regions based on a limited number of indicators.
[3] Source: European Commission - https://interactivetool.eu/EIS/EIS_2.html#a

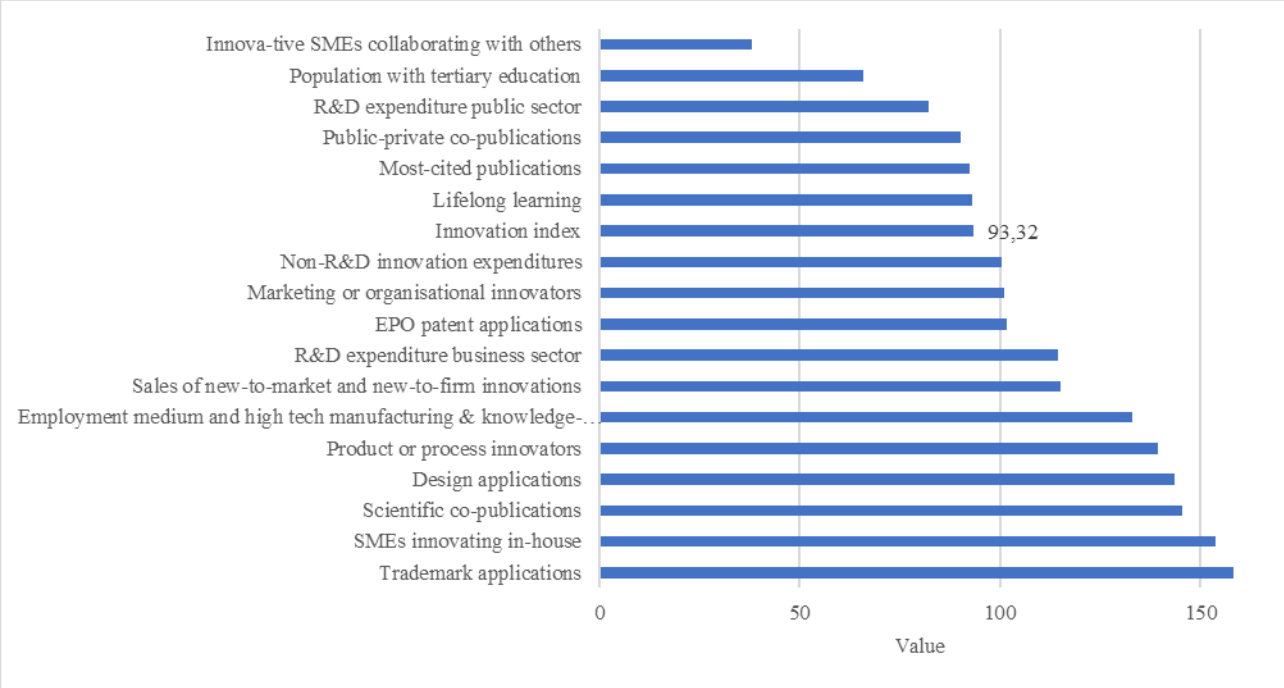


Fig. 2 Regional Innovation Scoreboard - Source: European Commission[4], 2019c

The regional GDP is by 27% represented by the manufacturing sector. According to the latest available data provided by the Chamber of Commerce (Unioncamere, 2019), 42.916 companies are active in the manufacturing sector (corresponding to 10,6% of the regional economy). A huge contribution is given by the so-called **Packaging Valley,** characterized by high expertise in innovative packaging machinery manufacturing. This benchmark sector is composed of design, manufacturing and trade of machinery, plants, apparatus and equipment in general for packing, packaging and refilling, in addition to design services, labelling, distribution and sales. According to the National Association of Packaging Machinery Manufacturers (UCIMA[5]), in the packaging valley are located 36% of Italian firms working in the sector with a contribution of 61,1% to the total turnover (Bentivogli et al., 2018). According to PARIX and AIDA databases[6], the packaging valley includes 339 companies working on packaging machinery manufacturing (according to 282930, 289500, 289600 Statistical classification of economic activities in the European Community (NACE)). The highest concentration of companies in this sector is in the province of Bologna, followed by Parma and Modena. Other districts in the sector are located in Reggio Emilia and Rimini. The entire packaging machinery manufacturing industry contributes to the prosperity of plastic packaging industry that accounts for 126 companies in 2018[7].

→ Since the plastic packaging industry is one of the drivers of the regional economy, system innovation has been applied to the ERR in order to take up the challenges of the present time and take advantages from the rethinking of current production, consumption and disposal patterns. The work completely fits with the ST and LT objectives, as respectively fixed within the Regional Waste Plan and the EU legislation on CE and plastics.

[4] Source: European Commission - https://interactivetool.eu/EIS/EIS_2.html#a
[5] Source: UCIMA - http://www.ucima.it/uc-en/
[6] PARIX and AIDA are databases containing economic and financial information at regional and national level. Source: https://www.bvdinfo.com/it-it/le-nostre-soluzioni/dati/nazionali/aida. PARIX has been substituted by ADRIER database – Source: https://adrier.lepida.it/AdriWeb/
[7] Data are provided by the Chamber of Commerce – Bologna.

1.2 System innovation theory

The variety of plastics, the multitude of plastic applications and the high number of stakeholders involved in the plastic packaging and plastic packaging waste system need a simplification in comprehensiveness of that systemic complexity (Iacovidou et al, 2017). In addition, the impact of plastics along the value chain requires a deep rethinking in accordance to the life cycle approach thus overcoming the lacking coherence of current research that generally examines the impacts dealing with one particular aspect, or stage on the plastic value chain (Hahladakis and Iacovidu, 2019).
An innovation orientation is likely to affect both forms of innovation presented in the literature: radical and incremental. **Radical innovations** cause disruptive change within the organization (Fairtlough, 1994). Incremental innovations are instead minor imperceptible changes that may have an impact as cumulative effect (Lawless and Anderson, 1996).
System innovations are designed to bring about a fundamental and radical change in the way societal functions are performed. Since the concept is still emerging and related processes are extremely complex, there is no consensus on the exact definition of system innovation (OECD, 1997). However, system innovation encompasses technological or social innovation. When innovation penetrates in a system, it groups all important economic, social, political, organizational factors that may influence the development, diffusion, and use of that innovation. It is pursued by:

- involving a large number of actors
- considering a lot of variables
- combining different levels and types of innovation (Edquist, 2001).

Therefore, system innovation works in a multi-actor process where variables are independent from each other but influence each other through interaction. This interaction implies the usage of different types of knowledge and skills not only from different stakeholder groups but also from different disciplines. This means that system innovation is not only multi-disciplinary, but also trans-disciplinary.
In order to make this complexity understandable, the establishment of strategic goals and objective allows to the main elements characterizing the system to establish a common path to follow. That objectives and goals are generally LT oriented as aimed to radically change the current situation. That transition to completely new system represents scientifically based synthesis which includes forecasting, planning and implementation of strategic goals and objectives.

→ Defining a unique plastic value chain is difficult given the wide number of applications. As aforementioned, this thesis is focused on packaging sector. System innovation has been applied to the **plastic packaging value chain in ERR.** In particular, socio-technical innovation is here implemented to improve the packaging design and the plastics circularity as well as the system in which packaging works. The goal is setting the basis for a radical change in the current production and disposal patterns by promoting an efficient after-use plastics economy.

1.3 Backasting method

System innovation needs a clear and coherent final goal to pursue. As described above, a vision, and consequently scenario, should be envisioned. Scenario development is emerging as a key method when, like in this case, uncertainty is high, the problem is complex and a LT view is essential (Kok et al., 2011).
To apply the backcasting method, two main aspects have to be considered:

- the type of scenario to envision
- the way to reach that scenario

Concerning the first aspect, the different way to approach the future are related to the following questions:

- **What will happen?** is responded to by Predictive scenarios. It is used to predict the future by defining forecasts and what-if scenario.
- **What can happen?** is responded to by Explorative scenarios. The scenarios could be used when several possible futures have been analysed.
- **How can a specific target be reached?** is responded to by Normative scenarios. Such studies are explicitly normative, since they take a target as a starting point.

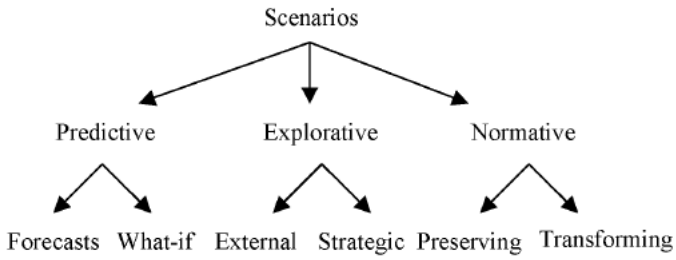


Fig. 3 Type of scenario categories – Source: Börjeson et al., 2006

The normative scenario has been selected and used to identify the goal to achieve within this thesis project. This category is divided into:

- **preserving scenario**
- **transforming scenarios** (Börjeson et al., 2006)

Transforming scenario is what EC is addressing by introducing the first EU-wide policy framework adopting a material-specific life cycle approach on plastics. The legislative framework sets ambitious targets that aim to completely change the current production, consumption and disposal system. These targets are established by EU bodies within the *Circular Economy package* and the *Plastics Strategy* with the final purpose to reach a more circular plastic system by 2030.

The overarching goals are here summarized and listed:

- Prevent the leakage of plastic in the environment
- Improve the resource efficiency
- Improve the circularity of plastics

Concerning the second aspect, four possible ways can be followed:

- **forecasting**
- **scenario forecasting**
- **backcasting**
- **participatory backcasting**

As illustrated in the figure below (Fig. 4), forecasting is the process of trend identification (Vergragt and Quist, 2011). The result of the forecasting approach is the development of the most likely picture of the future. This approach is recommended in the relatively stable external environment as BaU is the basis principle. The method of scenario forecasting, which involves the development of several alternative options for the future, allows to give recommendations on a strategy development in a changing environment. The backcasting method starts with defining a desirable future and then works backwards to identify policies and programs that will connect that specified future to the present. Participatory backcasting is characterized by the fact that, in addition to the expert's opinions, the interests and targets of a wide range of stakeholders are taken into account during the co-creation process of the desired future vision.

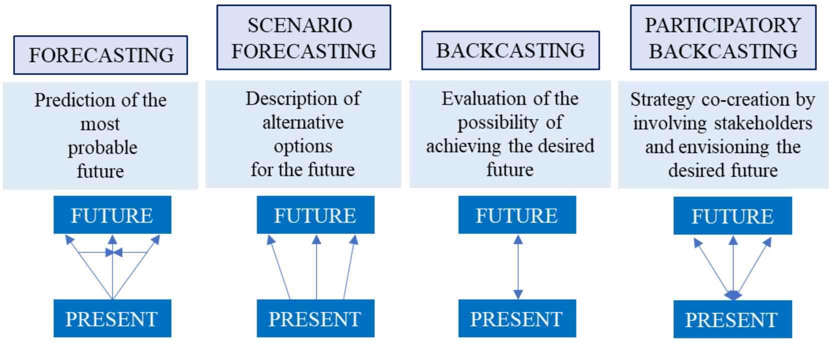


Fig. 4 Types of future scenario

The **normative scenario** is often directed towards how the final goal and the relative targets may be reached. As described above, that normative scenario refers to the transposition of EU measures and targets into regional policy where existing legislative framework is also considered.

Policy makers increasingly recognize the role that regions play in cultivating, attracting and retaining innovative economy and society (OECD, 2013). It is particular important when political commitment aims to ensure LT and cross-border efforts. In this framework, regional development policies increasingly focus on integrated policies portfolios to promote the complementary of policy in a given place (OECD, 2011).

→ Plastic is under investigation at multiple level of operability. EC has established a framework of measures within the *Circular Economy Action Plan* and the *Strategy for plastics in a circular economy*. The 2030 targets established in that policies have been identified as the final goals. Since the EU policies have to be transposed in each EU MS, the analysis has been conducted at sub-national level (ERR in this case) with the aim to study the contribution of regions in promoting a radical change in plastic packaging value chain. The main goal is having **100% recyclable (or reusable) plastic packaging by 2030.** This goal leads to an additional objective that is an increase in the **plastic packaging recycling rate** (whose target has been established for the same year, accounting for 55%). In addition, ST objectives have been fixed. The 2020 generation, collection and recycling targets defined within the Regional Waste Plan have been defined as ST objectives in this work. Therefore, the local context as well as the broader EU one has been deeply analysed to understand how regional and EU policies influence each other in achieving the goals. Region become a sort of laboratory where testing innovation and its dissemination in a wider system. From the transition engineering theory, region can be considered as a niche (Raven et al., 2010).

Future is affected by a multitude of factors: global economic situation, climate change, state of innovation and lifestyle (Rahimifard et al., 2013). Each factor may differently affect different area. Embracing a systemic multi-criteria concept that encompasses environment, human well-being, equity, human development, and economy is pursued through the backcasting method. As opposed to forecasting method (Robinson, 1990, Kishita et al, 2016), backcasting firstly defines a desirable future, then looks backwards from that future to the present in order to strategize and to plan how it could be achieved (Quist and Vergragt, 2006; Giddens 2008). It links the current situation to the envisioned sustainable future.

Since backcasting enhances the possibility of identifying radical innovations and changes in the future compared to thinking from the present situation (Quist, 2007), it is particularly suitable for system innovation by which pushing the transition of the current plastics production, consumption and disposal towards a more an after-use plastic economy. It is also useful because of:

- the complexity of the problem and in particular of the plastic_based materials system
- The need of major change for reducing dependence from fossil feedstock, pollution in manufacturing and disposal phases as well as the amount of landfilled and incinerated waste
- the need to change the dominant trends affecting the current life-style
- the lack of assessing externalities, especially in chemical industry that is a big part of the EU plastics industry
- the dimension and time of the scope that are wide and long enough to leave considerable room for deliberate choice (Dreborg 1996).

A major difference between visions and backcasting is that backcasting is not only about developing a vision, but also about developing strategies and pathways how to eventually achieve those visions. (Vergragt and Quist, 2011). It follows that scenario is not a prediction since it aims to develop an alternative future that may happen by understanding the current situation and planning the steps to achieve the desirable scenario.

→ In order to achieve the desirable future (identified as the normative one), a comprehensive analysis of the present situation (2017) and in particular the identification of the gap between the present and the future (2030) have been done. This work has been carried out by using a robust process named backcasting. Then, the **circularity strategy** has been proposed as way to achieve that future.

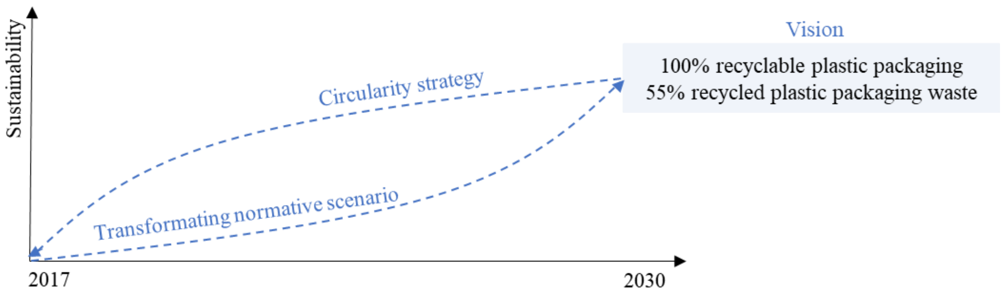


Fig. 5 Transforming normative scenario

Roorda (2014) has highlighted six principles that can influence the efficacy of transition experiments such as acknowledge the complexity of the challenges, recognize the difference between system optimization and system innovation, give room to diversity and flexibility, think systematically and co-create. All these principles are grouped and make operative through the backcasting methodology. The backcasting method is applied to the plastic_based materials system by considering the following steps:

(1) select a vision that is taken as end-point;
(2) define the principle that will guide the entire process
(3) delineate the system
(4) identify specific actors involved in the system
(5) describe the state of art and consequently the context in which the system works
(6) analyses barriers affecting the present situation and that hinder the future scenario achievement

(7) orientate the problem by identifying the obstacles to be overcome and the opportunities to be taken to realize the radical change

(8) define milestones

(9) implement the actions

(10) monitor that actions according to the final goal achievement (see Fig 6)

Fig. 6 Backcasting process

1.4 Participative backcasting formula

After the publication of *Our common future*, backcasting method was shifted towards sustainability (Robinson, 1990) and consequently participatory backcasting became known (Vergragt, 1993). It follows that participative backcasting becomes the method to envision and reach a sustainable plastic value chain. In particular, participatory backcasting aims at identifying and exploring sustainability solutions, towards broad stakeholder participation, and to multi-actor interaction process towards enhanced normativity of scenarios based on strong visions shared and supported by stakeholders, and to the importance of conceptual learning (Quist and Vergragt, 2006; Jacob et al., 2004). The tools and instruments usually used to implement participative backcasting method are workshops, focus group discussions, participatory mapping, and semi-structured interviews (Hagemeier, 2015).

The present work has engaged stakeholders through surveys, questionnaires, interviews and match-making workshop.

The overall phases and tools (both analytic and visual) used within this PhD work are summarized in the table below (Table 1).

Tab. 1 Phases and tools for the backcasting process implementation

Chapter	Step of the backcasting process	Key-findings	Analytic tool	Visual tool
5	**1. Future scenario envisioning**	Normative transforming scenario	EU, national and regional legislative analysis	
5	**2. Guiding principle**	Kuznet curve		
6	**3. System definition**	Regional plastic packaging value chain	Life cycle analysis	
	3.1 Stakeholder identification	Stakeholder mapping and analysis	Net map	
			Relevance-Interest Matrix	
			External, connected and core stakeholder schematization	
			Network stakeholder analysis	
	3.2 Stakeholder engagement	Participative backcasting process	Interviews	
			Questionnaires	
			Survey	
			Match-making event	
7	**4. System knowledge**	Present situation understanding		
	4.1 Quantitative analysis	Plastic packaging and plastic waste quantification	Material flow analysis	
	4.2 Qualitative analysis	Barriers analysis	Multi-level and multi-criteria analysis	
			PESTEL Analysis	
	5. Strategic problem orientation	Critical analysis		Context map
			Outside of inside Analysis	
			SWOT Analysis	
8	**6. Future solution envisioning**	Circularity strategy set up	Strategy planning	
8	**7. Implementation and monitoring**	Design for and from recycling - Recycling and Circularity		
9	**8. Follow up**	Conclusion		

The circularity strategy connects recycling with circularity in a life cycle approach by implementing eco-design for and from recycling. In addition, the strategy provides a tool which connects design and in particular, eco-design with recycling and circularity. While recycling throughput gives information about the amount, the value_based circularity indicator provides considerations on the quality of polymers and consequently on the market of SPs. The tool connects converters and recyclers with policymakers. The final goal is setting the basis for a radical change in the current production and disposal patterns by promoting an efficient after-use plastic economy in Emilia Romagna Region (ERR).

Summarizing, the tool contributes to:

- Support packaging designers to rethink plastic packaging with a view to the life cycle and, in particular, the EoL as link with the remanufacturing stage
- Standardize eco-design requirements for plastic packaging goods
- Incentivize the eco-design by implementing eco-modulation fees (as regards the Extended Producer Responsibility (EPR) principle that are in line with the recyclability principles
- Incentivize the use of PCR materials in new product manufacturing through economic incentives
- Harmonize the financial scheme of EPR system
- Connect recyclability with effective recycling
- Transpose EU recycling targets and therefore, harmonize the calculation of the recycling rate
- Measure the exact amount of plastic waste turned into SPs
- Link the quantity of SPs with its quality through the circularity indicator
- Give information on the SPs market trend through the circularity indicator
- Motivate recyclers in improving the recycling performance through the circularity indicator

2 PLASTIC MATERIALS AND APPLICATIONS

2.1 Plastic materials

The term "plastics" is adopted for classifying a wide range of materials basically characterized by high strength to weight ratio, versatility and resistance to any type of degradation (chemical, biological and physical).

The wide range of materials refers to polymeric materials of high molecular mass. A polymer is a useful chemical made of many repeating units[8]. The term **polymer** is defined in Article 3(5) of Regulation (EC) No 1907/2006 of the European Parliament and of the Council (2006) as a "*substance consisting of molecules characterised by the sequence of one or more types of monomer units. Such molecules must be distributed over a range of molecular weights wherein differences in the molecular weight are primarily attributable to differences in the number of monomer units. A polymer comprises the following: (a) a simple weight majority of molecules containing at least three monomer units which are covalently bound to at least one other monomer unit or other reactant; (b) less than a simple weight majority of molecules of the same molecular weight."* Each repeating unit is represented by a monomer able to be assembled in a complex organization such as the polymeric chain.

Polymers have a limitless range of characteristics:

- They are resistant to chemicals.
- They are insulators of heat and electricity.
- They are light in mass and have varying degrees of strength.
- They can be processed in various ways to produce fibers, sheets, foams, or intricate moulded parts.
- Their properties can be enhanced by additives.

However, even if some polymers can be efficiently work alone, others need additives addition. **Additives** improve specific properties such as hardness, softness, UV resistance, or their behaviour during manufacturing (Villanueva and Eder, 2014). The content of additives varies widely: from few percentages in PET to 60% in PVC (Villanueva and Eder, 2014).

Additives in plastic can be divided into:

- **Functional additives** (E.g. stabilisers, antistatic agents, flame retardants, plasticizers, lubricants, slip agents, curing agents, foaming agents, biocides, etc.)
- **Colorants**
- **Fillers** (E.g. mica, talc, kaolin, clay, calcium carbonate, barium sulphate)
- **Renforcements** (E.g. glass fibres, carbon fibres).

The mix between polymers and additives, is called **resin** (OECD, 2004). A resin is the result of different combinations of monomers and their blending with oxygen, chlorine, fluorine and nitrogen.

Plastics can be synthesized from fossil fuels as well as from biomass of different origin (E.g. Starch and sugars) or synthetized from fossil feedstocks.

[8] Source: American Chemistry - https://plastics.americanchemistry.com/plastics/The-Basics/.

A description of fossil_based plastics is included in the paragraph below (Paragraph 2.2). Bioplastics are not the core of this research and only few words are used to describe the them in the paragraph below.

2.2 Fossil-based plastics

According to the physical and chemical properties, fossil-based plastics can be:

- **Thermoplastics** represent the majority of polymeric materials. They came from a direct process. They are characterized by chemical stability over a wide range of temperatures. Thermoplastics can be remolten, therefore recycled, into new objects. Materials suffer degradation after several recycling cycles, however, at least theoretically, remanufacturing is admitted. Examples of thermoplastics are PET, PVC, PE (-LD or -HD), PP, PS, EPS, PLA, PHA, PC, PMMA, PA, PTFE, as shown in the Tab 2.
- **Thermosets** are produced after a chemical catalysed reaction that takes place during moulding in order to perform the polymeric chain with the formed plastic polymer chain. Thermoset plastic is a category of plastics unable to be reshaped, remolten or remanufactured after the first hardening. In fact, their high cross-linked structure is characterized by high resistance to mechanical force, chemicals, wear and heat. Examples of thermosets are PU, PI and Epoxy Resins, as shown in the Tab 2.

The following table identifies thermoplastics and thermosetting polymers.

Tab. 2 List of thermoplastic and thermosetting polymers

Thermoplastic polymers		Thermoset polymers
Polyethylene terephthalate (PET)	PHA	Polyamide (PI)
Polyvinyl chloride (PVC)	Polycarbonate (PC)	Epoxy Resins
Low/High density Polyethylene (LD/HD-PE)	Polymethyl methacrylate (PMMA)	Polyurethanes (PUR,PU)
Polypropylene (PP)	Polyamides (PA)	Silicone
Polyester (EPS)	Polytetrafluoroethylene (PTFE)	Vinyl Ester
Polystyrene (PS)	Acrylonitrile butadiene styrene (ABS)	Urea Formaldeyhde Resin (UF)
Polylactic acid or polylactide (PLA)	Styrene-acrylonitrile resin (SAN)	Phenolic Resins
Polybutylene terephthalate (PBT)	Polyetheretherketone (PEEK)	Acrylic Resin
Thermoplastic elastomers (TPE)	Polysulfone (PSU)	Melamine Resin (MF)

Fossil based plastics degrades in long period. Degradability is independent from the source of the polymer, while it is affected by the polymeric molecular organization and surrounding environmental conditions:

thermoset polymers cannot be melted and reformed[9]. Regarding recycling of thermoplastics, a problem might be the shortening caused by ageing that avoid new linking with molecules by hooking together. Thermosetting plastics cannot be recycled mechanically, but only energetically valorised.

Fossil_based plastics are made from crude oil. Almost all plastics are currently derived from fossil sources (Villanueva and Eder, 2014). However, 2,11 Mt (corresponding to 1% of total market) of plastics coming from biological cycle is nowadays used (European Bioplastics, & Institute for Bioplastics and Biocomposites, 2017).

Bioplastics are made from renewable materials such as corn, starch or non-food sources (Alvarez-Chavez et al.,2012; Di Gregorio, 2009; Mojo, 2007; Karana, 2012). Bioplastics can also be biodegradable. Depending on the degradation and the source, bioplastics can be:

- **Biodegradable plastics** degraded by microorganisms able to adopt them as substrate for their metabolism. Therefore, complex polymeric chain can be decomposed into water and carbon dioxide or methane, respectively with aerobic or anaerobic conditions. Biodegradable plastics can be synthetized either from biogenic or fossil feedstocks. PHA is an example of a bio-sourced plastic, obtained from bacterial synthesis, and biodegradable.
- **Bio-based plastics**, differently from biodegradable one, can be only synthetized from biogenic sources, even if the structure is identical to correspondent synthetic polymeric. However, even if the source is biogenic, they are not necessarily biodegradable. In fact, PLA, obtained from starch, is biodegradable, while Bio-PET, synthetized from sugars, cannot be biodegraded.

The following table shows the type of bio-polymers relative uses.

Tab. 3 List of bio-based polymers and related applications

BIO-BASED POLYMERS		
Name	Abb.	Main uses
Cellulose Acetate	**CA**	packaging
Polyamide	**PA**	fuel lines, pneumatic airbrake tubing, electrical cable ant termite sheathing, flexible oil and gas pipes, control fluid umbilical’s, sports shoes, electronic device components, and catheters
Polybutylene Adipate Terephthalate	**PBAT**	cling wrap for food packaging, compostable plastic bags for gardening and agricultural use
Polybutylene Succinate	**PBS**	reusable horticultural crates and rigid food packaging with hinges
Polyethylene	**PE**	films (storage bags, pouches, packaging films), blow molded hollow parts such as beverage containers, automotive fuel tanks, injection molded parts, tubes
Polyethylene Terephthalate	**PET**	bottles
Polyhydroxy Alkenoate	**PHAs**	medical tool
Polylactic Acid	**PLA**	films, fibres, plastic containers, cups and bottles
Polypropylene	**PP**	medical products (withstand the heat in an autoclave) and dishwasher safe containers
Polyvinyl Chloride	**PVC**	pipes, wires, films, cables and bottles
Polyurethane	**PUR**	mattress
Starch Blends		drug capsules by the pharmaceutical sector, blends for industrial applications

[9] Source: University of Southern California - http://illumin.usc.edu/7/recycling-plastics-new-recycling-technology-and-biodegradable-polymer-development/2/

The following table helps to identify the degradability of fossil_based polymers compared with the bio-based ones.

Tab. 4 Degradability of bio-based and fossil-based polymers - Source: European Bioplastics

	NON-BIODEGRADABLE	BIODEGRADABLE
BIO-BASED	Bio-PE Bio-PA Cellulose-Acetate	PLA PHA TPS
FOSSIL_BASED	PE-LD PE-HD PP PA PS PVC EVOH	PBAT PVA

In the end, it is possible to distinguish three main groups:

- Biobased or partially biobased non-biodegradable plastics such as biobased PE, PP, or PET (so-called drop-ins) and biobased technical performance polymers such as PTT or TPC-ET;
- Plastics that are both biobased and biodegradable, such as PLA and PHA or PBS;
- Plastics that are based on fossil resources and are biodegradable, such as PBAT.

2.3 Manufacturing of fossil_based plastics

Oil and natural gas are the major raw materials used to manufacture plastics (American Chemistry council[10]). Crude oil is a complex mixture of thousands of compounds and needs to be processed before using it. Crude oil is firstly subjected to distillation in an oil refinery where the heavy crude oil is separated into groups of lighter components, called fractions. Each fraction is a mixture of hydrocarbon chains (chemical compounds made up of carbon and hydrogen). One of these fractions, naphtha, is the crucial compound for the production of plastics.

The main processes involved in the plastic manufacturing are:

1. **Distillation/Cracking**
2. **Polymerization/Polycondensation**
3. **Compounding**
4. **Conversion**

The layout is shown in the Figure below (Figure 7).

[10] Source: American chemistry - https://plastics.americanchemistry.com/

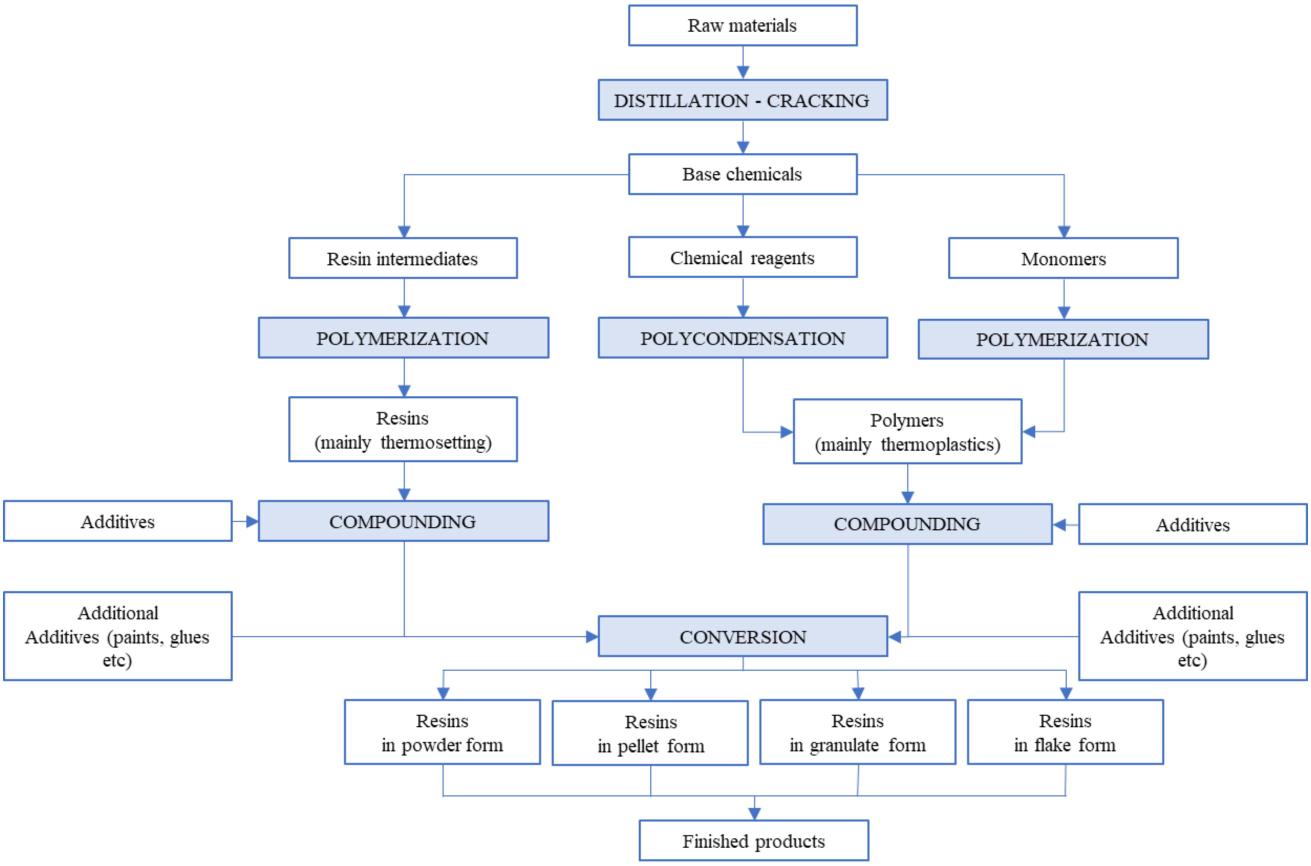


Fig. 7 Layout of plastics manufacturing process

a. Polymers manufacturing: from cracking to polymerization processes

As already mentioned, oil and gas are initially cracked to produce a range of products from which naphtha. Naphtha feedstock is either cracked or reformed to provide some intermediates. The transition from monomer to polymer is accomplished by polymerisation and blending activities. In a polymerisation reactor, monomers such as ethylene and propylene are linked together to form long polymer chains. Each polymer has its own properties, structure and size depending on the various types of basic monomers used.
Few types of polymers contain only carbon and hydrogen atoms. PE, PP, PS and are examples of these.
The combinations of monomers and their blending with oxygen, chlorine, fluorine and nitrogen generates additional types of plastics (Harper, 2005; Rosato et al., 2000). For example, PVC has chlorine attached to the all-carbon backbone. Nylons contain nitrogen atoms in the repeat unit backbone. PS and polycarbonates contain oxygen in the backbone. There are also some polymers that, instead of having a carbon backbone, have a silicon or phosphorous backbone.

Details are shown in the flow chart below (Figure 8).

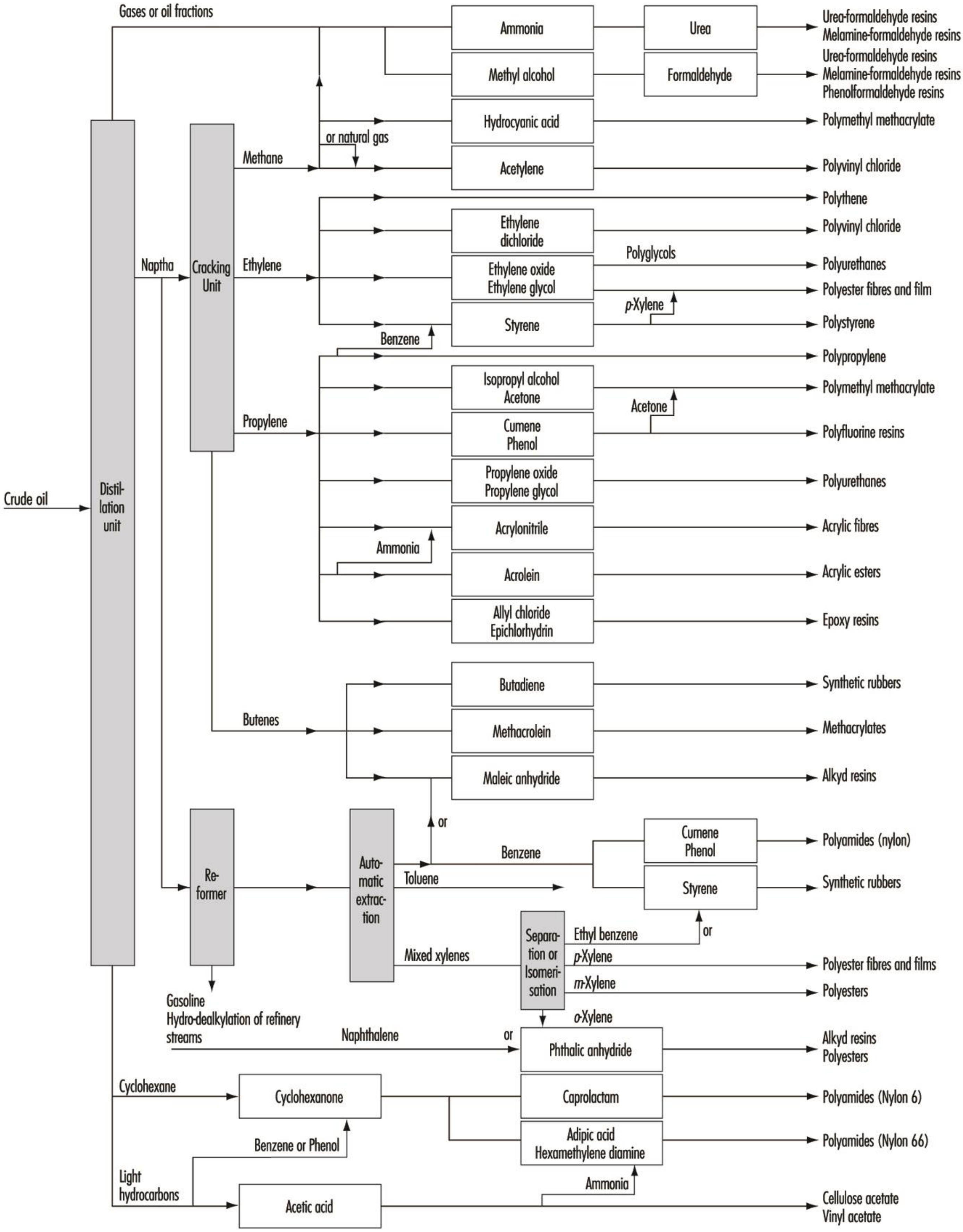

Gases or oil fractions
Ammonia
Urea
Urea-formaldehyde resins
Melamine-formaldehyde resins
Methyl alcohol
Formaldehyde
Urea-formaldehyde resins
Melamine-formaldehyde resins
Phenolformaldehyde resins
Hydrocyanic acid
Polymethyl methacrylate
or natural gas
Methane
Acetylene
Polyvinyl chloride
Polythene
Ethylene dichloride
Polyvinyl chloride
Naptha
Cracking Unit
Ethylene
Polyglycols
Ethylene oxide
Ethylene glycol
Polyurethanes
Polyester fibres and film
p-Xylene
Styrene
Polystyrene
Benzene
Polypropylene
Isopropyl alcohol
Acetone
Polymethyl methacrylate
Acetone
Propylene
Cumene
Phenol
Polyfluorine resins
Propylene oxide
Propylene glycol
Polyurethanes
Crude oil
Distil-lation unit
Acrylonitrile
Acrylic fibres
Ammonia
Acrolein
Acrylic esters
Allyl chloride
Epichlorhydrin
Epoxy resins
Butadiene
Synthetic rubbers
Butenes
Methacrolein
Methacrylates
Maleic anhydride
Alkyd resins
or
Benzene
Cumene
Phenol
Polyamides (nylon)
Re-former
Auto-matic extrac-tion
Toluene
Styrene
Synthetic rubbers
or
Ethyl benzene
Separa-tion or Isomeri-sation
Mixed xylenes
p-Xylene
Polyester fibres and films
m-Xylene
Polyesters
Gasoline
Hydro-dealkylation of refinery streams
o-Xylene
Naphthalene
or
Phthalic anhydride
Alkyd resins
Polyesters
Cyclohexane
Cyclohexanone
Caprolactam
Polyamides (Nylon 6)
Adipic acid
Hexamethylene diamine
Polyamides (Nylon 66)
Benzene or Phenol
Light hydrocarbons
Ammonia
Acetic acid
Cellulose acetate
Vinyl acetate

Fig. 8 Layout of polymers manufacturing – Source: Encyclopaedia of Occupational Health and Safety[11]

This research focuses the study only on plastic materials. Therefore, the following paragraphs show the processes to compound plastic resins and converts plastics in components and final products.

b. Plastics compounding

Compounding consists of the mixing and/or blending the polymer with additives to obtain the so-called **compound** characterized by a molten state. This process changes the physical, thermal, electrical or aesthetic characteristics of the plastics. In particular, additives are used to:

- protect plastics from the degrading effects of light, heat, or bacteria
- to change such plastic properties, such as melt flow
- to provide colour
- to provide foamed structure
- to provide flame retardancy
- to provide special characteristics such as improved surface appearance or reduced tack/friction
- to increase flexibility and workability (American chemistry council[12])

c. Plastics conversion

The conversion of plastics materials into finished products can be done through different processing methods. As detailed below, different processes exist:

- **Compression moulding**

This process consists of heating a plastic material, which can be in the form of granules or powder, in a mould which is held in a press. When the material becomes "plastic" the pressure forces it to conform to the shape of the mould. If the plastic is of the type that hardens on heating, the formed article is removed after a short heating period by opening the press. The main applications are bottle caps, jar closures, electric plugs and sockets, toilet seats, trays and fancy goods. Compression moulding is also employed to make sheet for subsequent forming in the vacuum forming process or for building into tanks and large containers by welding or by lining existing metal tanks.

- **Injection moulding**

In this process, plastics granules or powders are heated in a cylinder (known as the barrel), which is separate from the mould. The material is heated until it becomes fluid, while it is conveyed through the barrel by a helical screw and then forced into the mould where it cools and hardens. The mould is then opened mechanically, and the formed articles are removed. The main applications include the manufacturing of wire spools, packaging, bottle caps, automotive dashboards, pocket combs.

- **Extrusion**

This is the process in which a machine softens a plastic and forces it through a die which gives it the shape that it retains on cooling. The process of extrusion has two major types. In one, a flat sheet is produced. This sheet can be converted into useful goods by other processes, such as vacuum forming. The second is a process in which the extruded tube is formed and when still hot is greatly expanded by a

[11] Source: Encyclopaedia of Occupational Health and Safety - http://www.iloencyclopaedia.org/part-xii-57503/chemical-processing/128-examples-of-chemical-processing-operations/plastics-industry
[12] Source: American chemistry council - https://plastics.americanchemistry.com/

pressure of air maintained inside the tube. Tubes for industrial or domestic, film for wrapping in packaging applications are generally extruded.

- **Calendering**

In this process, a plastic is fed to two or more heated rollers and forced into a sheet by passing through a nip between two such rollers and cooling thereafter. The main applications are sheet (thicker than films) for industrial and domestic applications. Calendering is also used to process raw material in the manufacture of clothing and inflated goods such as toys.

- **Blow moulding**

This process can be regarded as a combination of the process of extrusion and thermo-forming. A tube is extruded downwards into an opened mould as it reaches the bottom the mould is closed round it and the tube expanded by air pressure. Thus, the plastic is forced to the sides of the mould and the top and bottom sealed. On cooling, the article is taken from the mould. TBlow moulding is used to manufcature bottles, including PVC bottles used for carbonated drinks.

- **Rotational moulding**

This process is accomplished by heating and cooling a hollow form which is rotated to enable gravity to distribute finely divided powder or liquid over the inner surface of that form. The main applications are footballs, dolls and other similar articles manufacturing.

- **Film casting**

This process consists of extruding a hot polymer on to a highly polished metal drum, or a solution of polymer can be sprayed on to a moving belt. This process is used to manufacture multi-composite films made up of plastics and board/paper used for packaging applications.

- **Thermo-forming**

Under this heading are grouped a number of processes in which a sheet of a plastic material, more often than not thermoplastic, is heated, generally in an oven, and after clamping at the perimeter is forced to a predesigned shape by pressure which may be from mechanically operated rams or by compressed air or steam. For very large articles the “rubbery” hot sheet is manhandled with tongs over formers. External light fittings, advertising and directional road signs, baths and other toilet goods and contact lenses are generally thermo-formed.

- **Vacuum-forming**

In this process a sheet of plastic is heated in a machine above a cavity, around the edge of which it is clamped, and when pliable it is forced by suction into the cavity, where it takes some specific form and cools. In a subsequent operation, the article is trimmed free from the sheet. This process is used for cheaply thin-walled containers of all types, as well as display and advertising goods, trays and similar articles, and shock-absorbing materials for packing goods such as fancy cakes, soft fruit and cut meat.

- **Laminating**

In this laminating processes, two or more materials in the form of sheets are compressed to give a consolidated sheet or panel of special properties. Decorative laminates made from phenolic and amino resins, at the other complex films used in packaging having, for example, cellulose, polyethylene and metal foil in their constitution. Are generally laminated.

2.4 Fossil-based plastics applications

Since the research focused on fossil_based polymers, the following tables (Tables 5 and 6) shows some example of commodity, engineering and specialist polymers (high performance plastics) and the relative applications.

Tab. 5 List of commodity and engineering polymers

COMMODITY/STANDARD and ENGINEERING POLYMERS		
Name	**Abb.**	**Main applications**
Polyamides	**PA or nylons**	Fibres, toothbrush bristles, tubing, fishing line and low-strength machine parts such as engine parts or gun frames
Polycarbonate	**PC**	Compact discs, eyeglasses, riot shields, security windows, traffic lights and lenses
Polyester	**PES**	Fibres and textiles
Polyethylene	**PE**	Supermarket bags and plastic bottles
High-density polyethylene	**HDPE**	Detergent bottles, milk jugs and moulded plastic cases
Low-density polyethylene	**LDPE**	Outdoor furniture, siding, floor tiles, shower curtains and clamshell packaging
Polyethylene terephthalate	**PET**	Carbonated drinks bottles, peanut butter jars, plastic film and microwavable packaging
Polypropylene	**PP**	Bottle caps, drinking straws, yogurt containers, appliances, car fenders bumpers and plastic pressure pipe systems
Polystyrene	**PS**	Foam peanuts, food containers, plastic tableware, disposable cups, plates, cutlery, compact-disc, CD and cassette boxes
High impact polystyrene	**HIPS**	Refrigerator liners, food packaging and vending cups
Polyurethanes	**PU**	Cushioning foams, thermal insulation foams, surface coatings and printing rollers
Polyvinyl chloride	**PVC**	Plumbing pipes and guttering, electrical wire/cable insulation, shower curtains, window frames and flooring
Polyvinylidene chloride	**PVDC**	Food packaging
Acrylonitrile butadiene styrene	**ABS**	Electronic equipment cases (E.g. computer monitors, printers, keyboards and drainage pipe)
Polycarbonate/Acrylonitrile Butadiene Styrene	**PC/ABS**	Car interior and exterior parts, and mobile phone bodies
Polyethylene/Acrylonitrile Butadiene Styrene	**PE/ABS**	Low-duty dry bearings, as slippery blend

Tab. 6 List of specialist polymers (high performance polymers)

SPECIALIST/HIGH PERFORMANCE POLYMERS		
Name	**Abb.**	**Main applications**
Polyepoxide	**EPOXY**	Adhesive, potting agent for electrical components, and matrix for composite materials with hardeners including amine, amide, and boron trifluoride
Polymethyl methacrylate	**PMMA**	Contact lenses of the original "hard" variety, glazing, aglets, fluorescent light diffusers, rear light covers for vehicles
Polytetrafluoroethylene	**PTFE or Teflon**	Heat-resistant and low-friction coatings, things like non-stick surfaces for frying pans, plumber's tape and water slides
Phenolics or phenol formaldehyde	**PF**	Insulating parts in electrical fixtures, paper laminated products, thermally insulation foams
Melamine formaldehyde	**MF**	Mouldings (E.g. break-resistance alternatives to ceramic cups, plates and bowls for children) and the decorated top surface layer of the paper laminates
Urea-formaldehyde	**UF**	Wood adhesive for plywood, chipboard, hardboard and electrical switch housings.
Polyetheretherketone	**PEEK**	Medical implant applications, aerospace mouldings
Maleimide/bismaleimide	**BMI**	
Polyetherimide	**PEI Ultem**	

2.5 Plastic value chain

This paragraph aims to illustrate a simplified version of plastic value chain.

As shown in the Figure 9, the plastic value chain involves different players:

- **Raw materials producers** that extract fossil fuel, apply steam cracking process and produce monomer and polymers
- **Compounders** that mix polymers with additives, depending on the requirements necessary to perform articles and products
- **Converters**, that perform articles and products, mainly in packaging, building and construction (B&C), automotive, electrical-electronic (EE) manufacturing sectors
- **Distributors**
- **Users and consumers**
- **Collectors** that manage products when has become waste
- **Recyclers and general waste operators** that dispose waste in landfill or valorise it in incineration (with energy recovery) or in recycling plants (with secondary plastics manufacturing).

The following figure describe the main actors involved in the plastic value chain.

Fig. 9 Simplified plastic value chain

Details on plastic industry are listed in the sub-paragraphs below. A description of EU as well as Italian blueprints are included.

2.5.1 Petro-chemical industry

As described above, the production of fossil-based plastics is based on steam cracking process. Steam cracking is the petrochemical process in which saturated hydrocarbons are broken down into smaller, often unsaturated, hydrocarbons. It is the principal industrial method for producing the lighter alkenes (or commonly olefins), including ethene (or ethylene) and propene (or propylene). Monomers are then polymerised to produce resins.

According to the British Plastics Federation[13], only 4% of the world's oil extracted is used to manufacture plastics. The remains are mainly used for chemical industry (4%), heating and energy applications (42%) and transportation sector (45%).

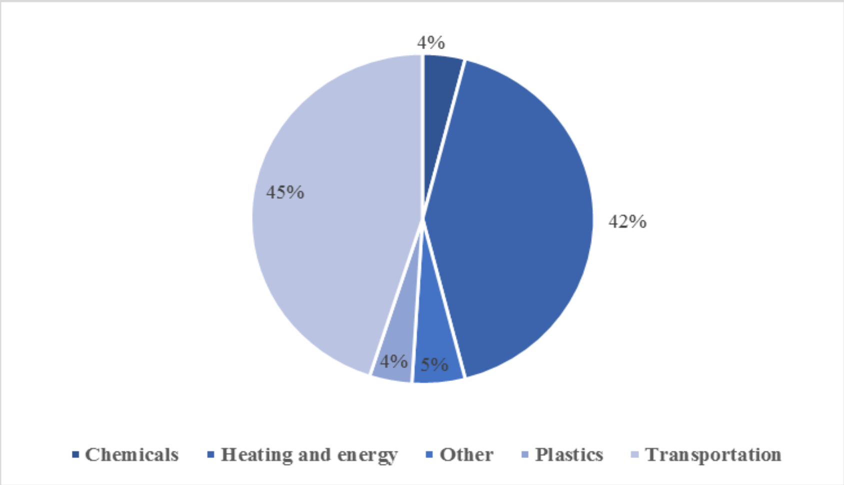


Fig. 10 Oil applications – Source: British Plastics Federation

The sales value of EU plastics producers is equal to €542 billion, less than half of what China produces (1.293 billion EUR), compared to the €3.475 billion sales at global level. From 1997 to 2017, the market share of the EU chemical industries has halved, going from 31% to 16%. EU petrochemistry accounts for 27% of sales and all polymers together (rubber- plastic plastics), are just over 20%[14]. The top trading partners for exports (in value) outside the EU were Turkey with over 13%, China with around 12% and USA with almost 12%. The main partners for imports from outside the EU were: USA with approximately 25%, Saudi Arabia with about 13% and South Korea with over 12%.

The following map shows the global production of ethylene, that is the main raw material used[15] to produce plastic materials.

[13] Source: British Plastics Federation - https://www.bpf.co.uk/

[14] Source: Polimerica.

[15] AMI is a database containing information on plastic processors, including market and production capacities – Source: https://www.ami.international/pubs/all?catalog=Publishing

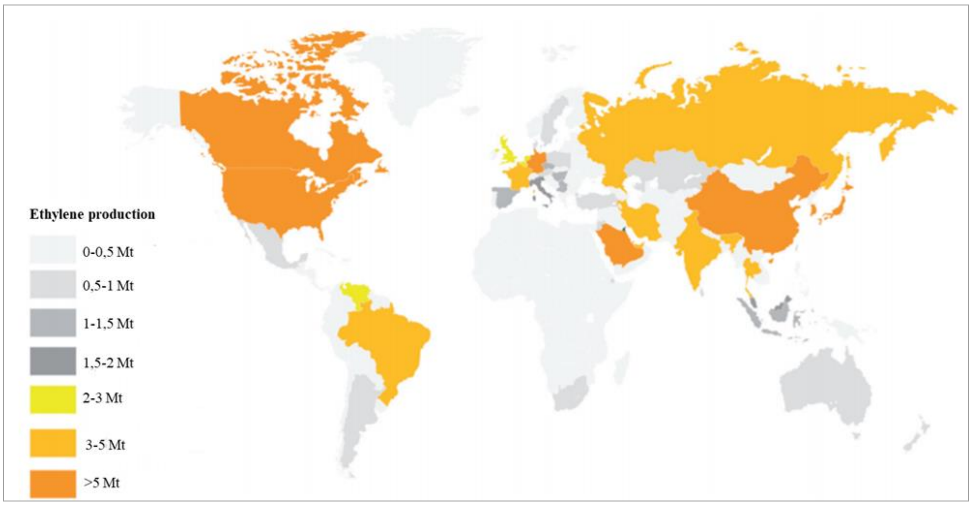


Fig. 11 Global generation of Ethylene, 2013 – Source: The European House – Ambrosetti, 2013

According to the Applied Market Information (AMI)'s database, the 10 largest companies of the global chemical industry are:

1) Dow Chemical (Michigan)
2) Lyondell Basell (Netherlands, Texas, UK)
3) Exxon Mobil (Texas)
4) SABIS (Saudi Arabia)
5) INEOS (Switzerland)
6) BASF (Germany)
7) **ENI (Italy)**
8) LG Chem (South Korea)
9) Chevron Philips (Texas)
10) Lanxess (Germany)

2.5.2 Compounding industry

Once the plastic resins have produced by the chemical polymerization, additives and other materials must be added to make resins commercially useful. The relatively industry is really complex, involving the manufacture of additives and modifiers. Plastic compounding is done by three different kinds of companies:

- resin producers (E.g. Borealis, Ineos and Lyondell Basell)
- plastics processors (that process and shape resins and compounds by injection or blow moulding, thermoforming and extruding) (E.g. Ravago, Cabot International, Schulman, PolyOne)
- independent compounders that offer fast colour-matching and high levels of service to local processors

Some companies do more than one of these activities and are named integrated compounders.

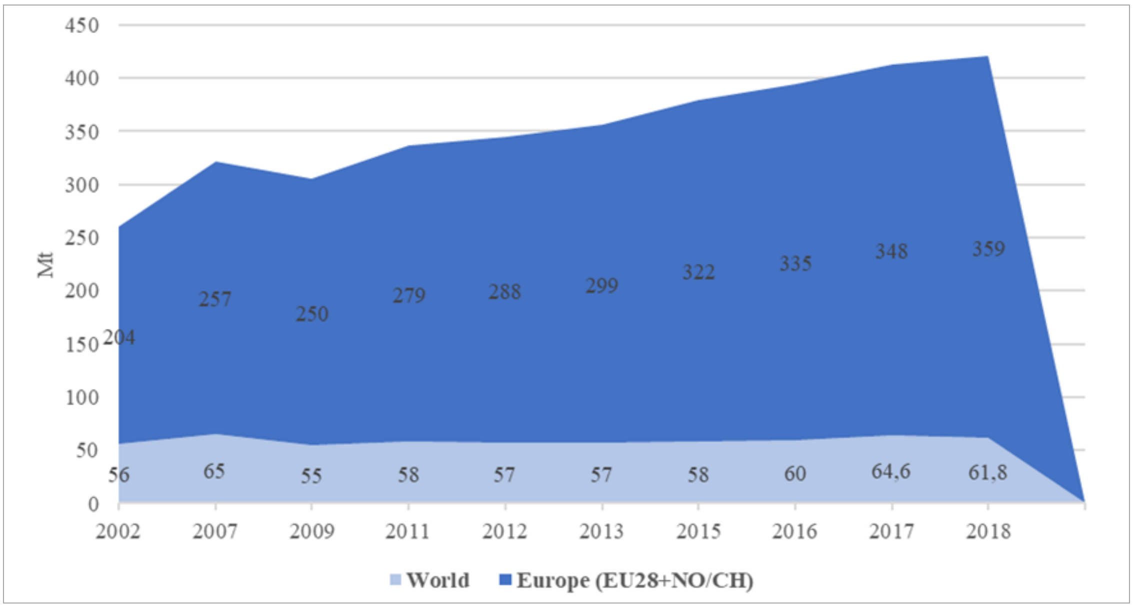
Nevertheless, a wide range of polymers exists, only PE, PET, PP, PVC, PS and EPS dominate the current market, accounting for 75% of total production (PlasticsEurope, 2018). In the recent years the EU compounding markets have increased owing to the growth of technical POs and engineering compounds demand as replacements for metals and other traditional materials in automotive and electrical applications. According to AMI's databases, more than 700 compounding sites are located in Europe, of which 98 are polymer manufacturers.

The top 10 independent compounding companies operating in the EU market are[16]:

1) Ravago (Belgium)
2) MBP Materie Plastiche Bresciane (Italy)
3) Polymer Chemie (Germany)
4) A Schulman (Germany)
5) **Sirmax (Italy)**
6) Inno-comp (Hungary)
7) Albis Plastic (Germany)
8) Sumika Polymer Compounds (UK)
9) Plalloy MTD (Netherlands)
10) **LAM Plast (Italy)**[17]

Integrated compounders account for around only 14% of compound operations in EU producing 50% of the market's materials in 2007; the biggest companies are Clariant and Cabot.

Considering the overall oil yearly used to produce plastics, the global plastic production accounted for 359Mt in 2018[18] (See Figure 12) (PlasticsEurope, 2019). As shown in the Figure, the EU plastics production has registered a reduction respect to the global one.



[16] Source: Plastemart - http://atozplastics.com/upload/literature/thermoplastic-compounding-business-growth-eastern-europe.asp

[17] Around 300 compounding sites are located in Italy (The European House – Ambrosetti, 2013)

[18] The trend includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers and do not inlude PET, PA and polyacryl-fibers.

Fig. 12 Global and European plastic production, 2002-2017[19] - Source: PlasticsEurope, 2015, 2016, 2017, 2018. Data have been elaborated by PlasticsEurope (PEMRG) / Conversio Market & Strategy GmbH

The following maps and graph report both 2017 and 2018 data. The comparison will help to motivate the EU plastics production registered in 2018. As shown in the Figure 13, the biggest plastic production is registered in Asia, followed by Europe and Nafta[20]. Minor amounts are produced in Africa, Latin America and CIS[21]. The comparative analysis reveals that Europe is the only state registering a reduction in the plastics demand in 2018.

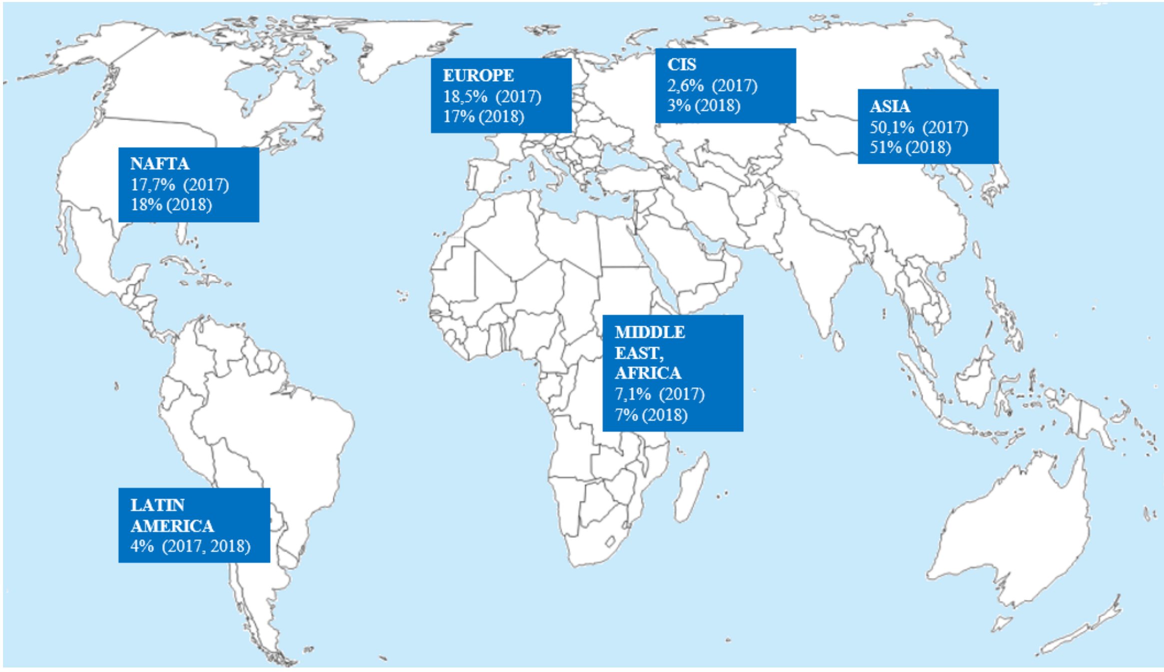


Fig. 13 Global plastic production, 2017, 2018 – Source: PlasticsEurope, 2018, 2019. Data have been elaborated by PlasticsEurope (PEMRG) / Conversio Market & Strategy GmbH

2.5.3 Conversion industry

Plastic conversion industry uses primary plastics to perform products for various appliances in customer industries.

The total demand of the EU plastic converter was 51,2Mt in 2017 and 2018[22]. It means that rhe reduction on plastics demand registered in the paragraph above is mainly due to a reduction in the export market. The biggest consumer was Germany, followed by Italy, France, Spain, UK, Poland, Belgium, Netherlands, Czech Republic, Austria, Sweden, Portugal, Hungary, Switzerland, Romania, Greece, Finland, Denmark, Slovakia registered a demand less than 2000Mt. Bulgaria, Ireland, Norway, Slovenia, Croatia have the smallest contribution (less than 500 Mt).

[19] Last available data (provided by PlasticsEurope).
[20] North America FreeTrade agreement.
[21] Commonwealth of Independent States.

[22] The study includes plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings and sealants) and does not include PET fibers, PA fibers, PP fibers and polyacryls-fibers.

Countries demanding more than 3Mt are reported in the Figure below (Figure 14). The EU country with the highest demand is Germany with approximately 25%, followed by Italy with over 14% and France with almost 10%. It follows that, to an EU plastics production reduction, the converters demand has not registered a significant change respect the previous year.

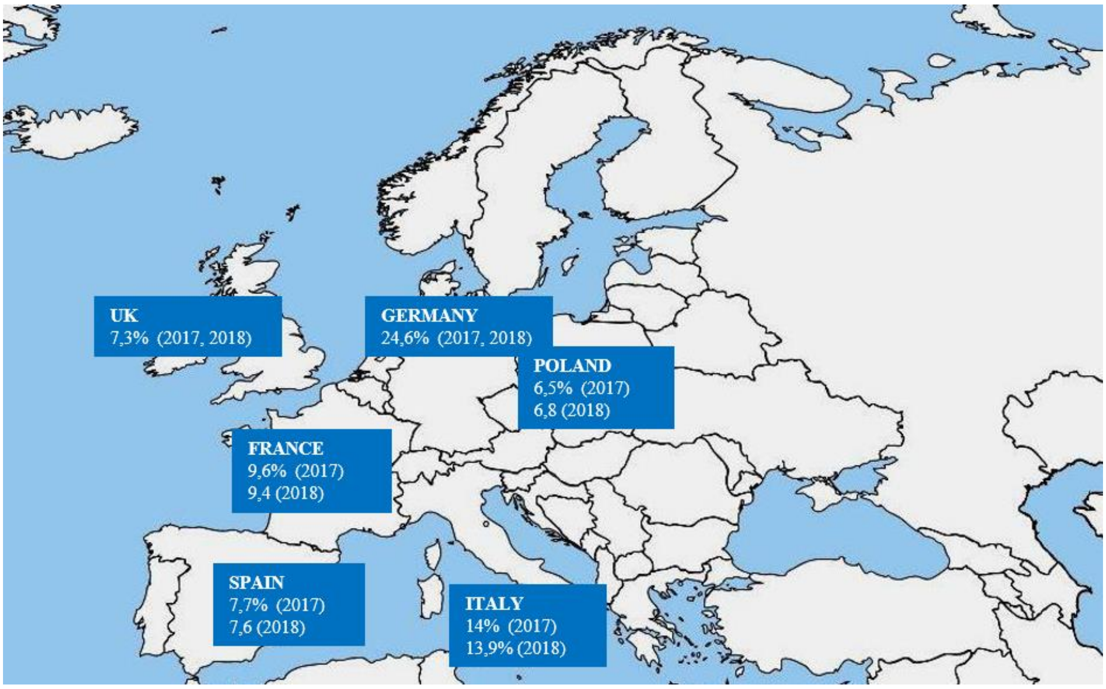


Fig. 14 Plastic demand in Europe (EU28+NO,CH), 2017, 2018 – Source: PlasticsEurope, 2018, 2019. Data have been elaborated by PlasticsEurope (PEMRG) / Conversio Market & Strategy GmbH

Considering the segment of application, packaging remains the most important application: it covered 39,7% of total EU demand in 2017 whit a small increase in 2018 (39,9%). Packaging is followed by B&C, EE, household, leisure and sports, agriculture. Data are illustrated in the Figure below.

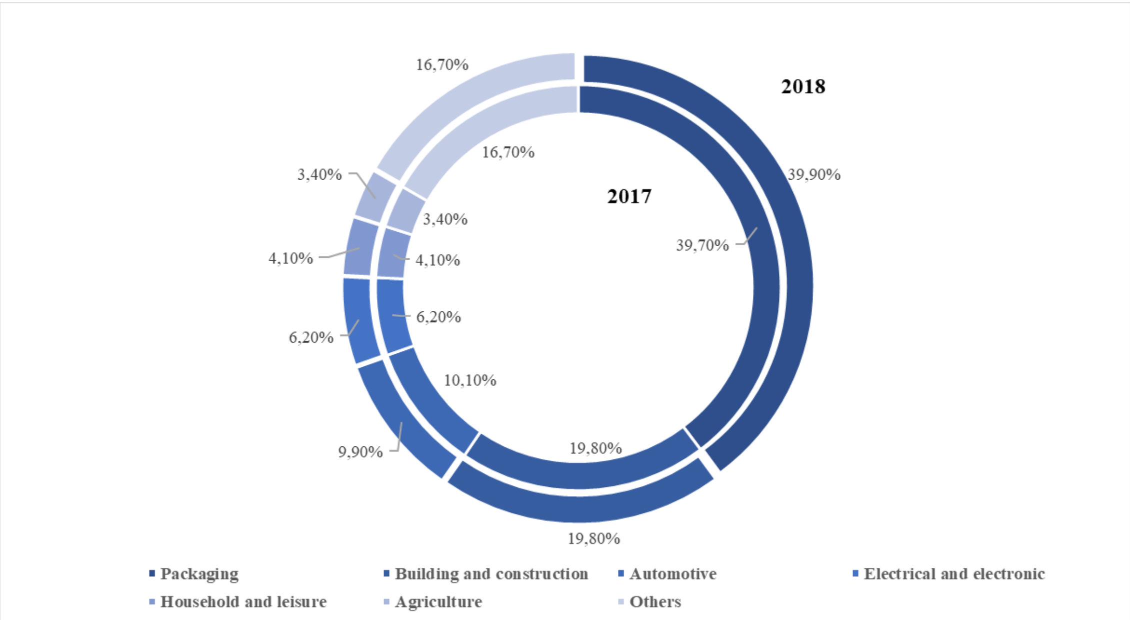


Fig. 15 Plastics demand in Europe (EU28+NO,CH), 2017, 2018. Analysis by sector – Source: PlasticsEurope, 2018, 2019. Data have been elaborated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH

Omitting data on fibres and additives production (that are not readily available), Figure 16 highlights the details of the resins type: PP and PE-LD are the most used polymers, followed by PE-HD, PVC, PUR, PET, and PS or expanded polystyrene (PS-E).

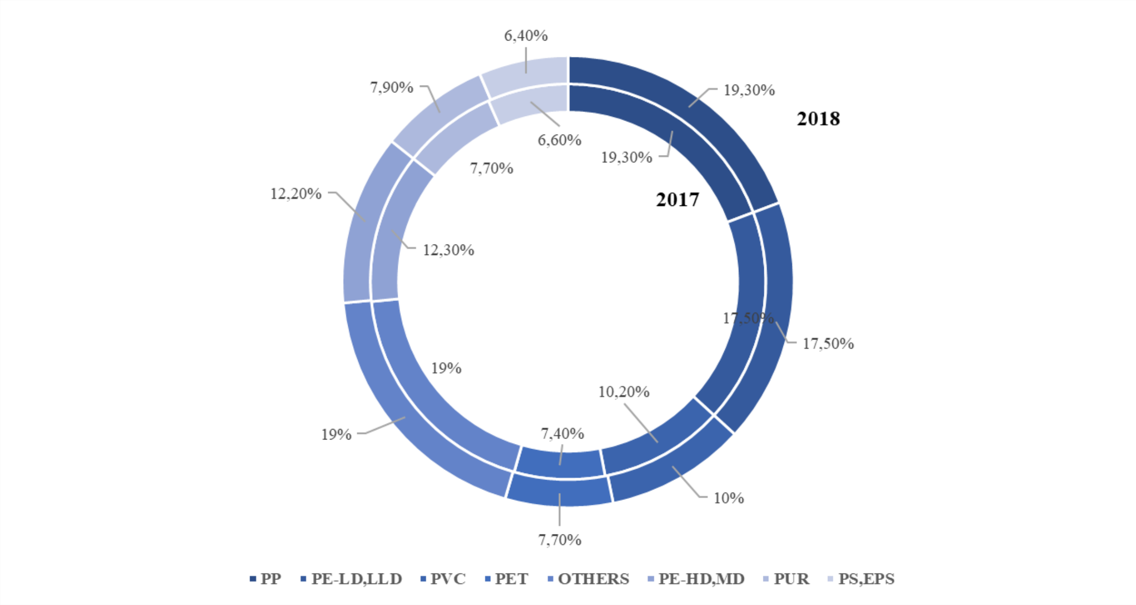


Fig. 16 Plastic demand in Europe (EU28+NO,CH), 2017, 2018. Analysis by polymer type - Source: PlasticsEurope, 2018, 2019. Data have been elaborated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy Gmb

The integration between polymer type and segment is illustrated in the graph below (Figure 17).

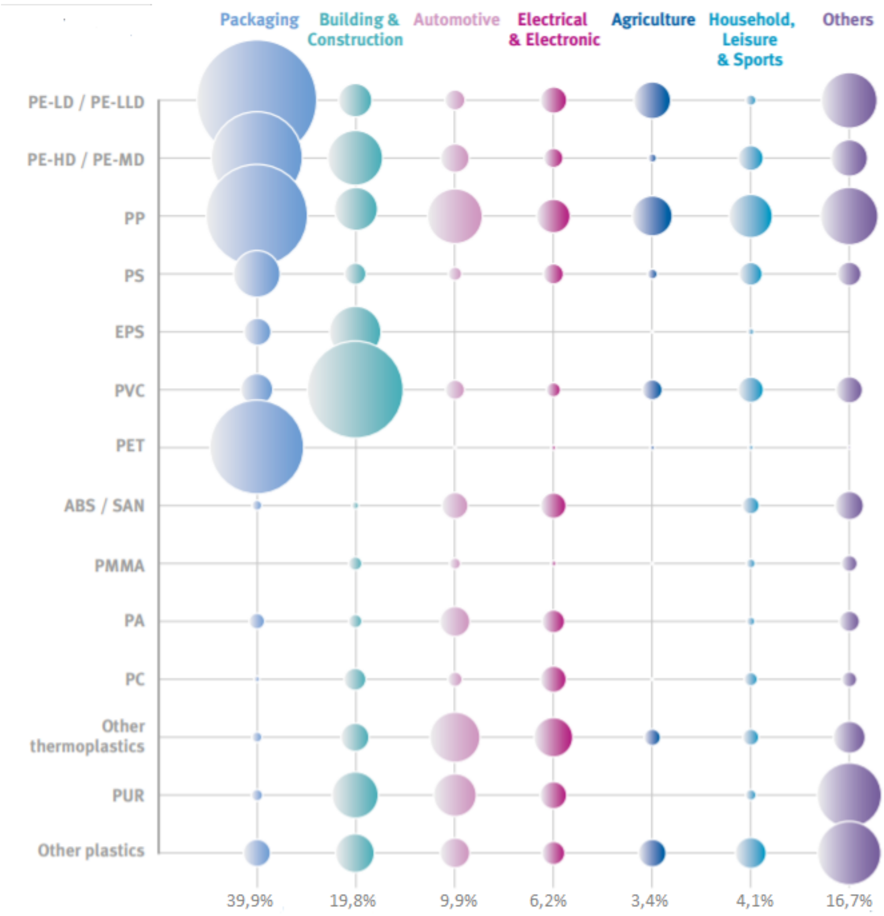


Fig. 17 Plastic demand in Europe (EU28+NO,CH), 2018. Analysis by segment and polymer type - Source: PlasticsEurope, 2019. Data have been elaborated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH

As shown in the Figure 17, PE, PP and PET are especially used in packaging sector. PVC is the main polymers used in B&C while automotive has been increasing the use of a huge variety of thermoplastic and thermosetting polymers. Is clear that packaging sector is the most demanding sector per plastic intensity. The same trend has been registered in the previous year (2017) (PlasticsEurope, 2018).

Since the thesis focuses on plastic packaging application, the following information refers to this sector.

At global level, the plastic packaging market was valued at close to USD 334,31 billion in 2018 (+4% respect to 2017)[23]. It is expected to reach USD 452,24 billion in 2024. Bottles covered the highest revenue in 2018, followed by bags and wraps and films. Asia Pacific accounted the largest market in the world, followed by North America.

The 10 largest plastic packaging converters in the word are:

1) Amcor (Switzerland)
2) Apla-Werke (Austria)
3) Coveris Holdings S.A (USA)

[23] Source: Zion Market Research - https://www.zionmarketresearch.com/news/plastic-packaging-market

4) Sealed Air Corporation (USA)
5) Rpc Group (UK)
6) Mondi Group (UK)
7) Aptar Group SAS (France)
8) Constantia Flexible holding (Austria)
9) Klockner Pentaplast (Germany)
10) Papier Mettler (Germany)

Most of them are located in Europe.

Around 9.410 conversion companies are located in Italy (The European House – Ambrosetti, 2013). In 2018, 5,75Mt of polymers are managed by the national industry. The market shows a reduction respect to 2017: the demand reduction has been registered for PP (30.000t), PVC (20.000t), PS (15.000t), PE (10.000t) and engineering polymers. The details are shown in the figure below.

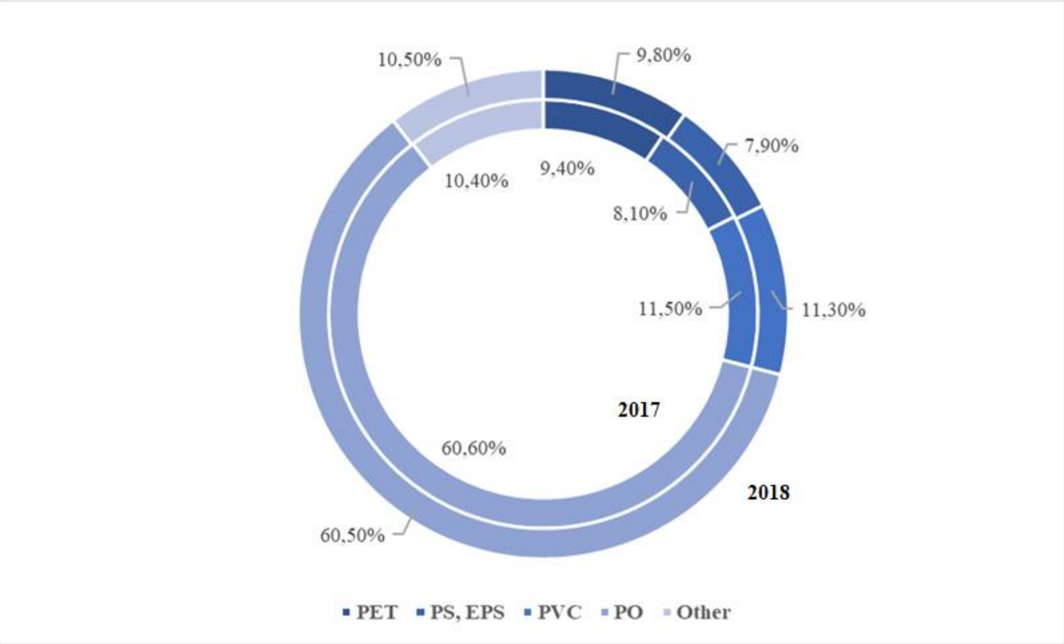


Fig. 18 Plastics demand in Italy, 2017, 2018. Analysis by polymer type – Source: Plastic Consult[24]

2.5.4 Plastic waste management system

Since several waste managers are involved in process by which waste plastics move from the place of generation to recycling facilities, the following discussion embraces the entire system of industry operating in waste management activities. The organization of EoL in MS depends significantly upon government rules and regulations. It contributes to differentiate the collection and recycling system.

According to local system, collection could be:

- **Kerbside collection**
- **Door-to-door collection**

[24] Plastic Consult – Source: http://plasticconsult.it/

- **Dropoff locations**
- **Refill/deposit system** (especially for PET bottles)

After the collection, plastic wastes are transported to the Material Recovery Facilities (MRF). Once the plastic waste reaches deposits or recycling facilities, the sorting activity is performed. Plastic wastes are firstly separated from non-plastic wastes and then sorted to obtain different polymers and colors. Several sorting techniques are available. One of the most used procedure to separate polymers is the density separation process[25].
Other separation processes are based on spectrophotometric density and magnetic properties. Eddy current separation is used to sort non-ferromagnetic objects. X-rays are also used for sorting very dirty bottles or those having large labels. Near infra-red rays (NIR) is a color-based sorting technology. Multiple detectors can be used to maximize the sorting performance (Hopewell et al., 2009). Another important step is represented by removal contamination removal. It could be macro-physical or chemical. Cleaning process is used to remove oil, solvents, paint, fatty foodstuffs or detergents absorbed by plastic (Villaneuva and Eder, 2014). It is important to remove water_based glue as well. Rigid plastics are then ground into flakes. Then, various methods exist for flake-sorting; sink/float separation separates PO from PVC, PET and PS; air elutriation removes low-density films from denser ground plastics (Roy and Brown, 2007); laser sorting differentiate polymer by type of grade.
After these steps, the recycling procedure takes place. Two main recycling technologies can be adopted, depending on origin and typology of plastic waste.
It is possible to distinguish:

- **Mechanical recycling.** It is recognized as the predominant technologies for recycling plastics and is carried out in four general stages: sorting, shredding (flaking), washing and drying, extrusion and agglomeration.
  After the sorting, the mainly singular polymer material is reduced in size for enhancing further processing. After being shredded in flakes, the material is washed and (theoretically) fully cleaned from impurities, such as food residues, labels and dirt. The cleaning process helps to separate polymers by density. Then, the material is commonly agglomerated for improving its density and increasing its viscosity as a consequence. Finally, the material is ready to be extruded obtaining the so-called strands. Materials ae finally filtered, cooled by water and cut into pellets.
  Thermosets are characterized by being unable to be re-melt, therefore, to be re-extruded. In this case they can be only grinded for producing a fine powder which can be used as filler mixed with virgin material.
- **Chemical recycling/Feedstock recycling.** This process allows to obtain simple monomers. The monomers obtained can be re-polymerized in order to create again new plastics. The process includes:

- Chemical depolymerization where plastic polymers (and in particular polyesters like PET and nylon[26]) react with chemical reagents.
- Thermal cracking where polymeric materials are converted into liquid petroleum products.
- Catalytic conversion where a catalytic cracking is implemented to produce gasoline and diesel fractions.
- Gasification to produce syngas by partial oxidation of organic matter at 1200-1500°C under mildly oxiding condition (Aguado et al., 2018).

[25] Polymers are characterized by different density. Density of some most common polymers are illustrated in the table below:

Tab. a. Density of the most common polymers

Polymer type	**HDPE**	**LDPE**	**PP**	**PVC**	**PET**	**Teflon**	**PC**
Density (g/cm^3)	0,95	0,92	0,91	1,44	1,35	2,1	1,2

[26] Chemical depolymerisation cannot be used to reprocess PE, PP or PVC.

As written by Hopewell et al. (2009), the ASTM D5033 defines four type of recycling, such as:

- **Primary recycling**, referring to closed-loop recycling
- **Secondary recycling**, referring to downgrading
- **Tertiary recycling** that is the chemical recycling

The study also defines the **quaternary recycling** as energy recovery[27].

The same authors have developed key-performance indicators (KPIs) assessing the performance of closed-loop recycling (CLR) g in accordance to the type of polymer (See Table 7).

Tab. 7 Effectiveness of closed loop recycling in current recycling process. Analysis by polymer type – Source: Hopewell et al., 2009

Polymer	Closed loop recycling	Effectiveness in current recycling process
PET	Yes	↑ with clear PET bottles
HDPE	Some	↑ with natural HDPE bottles ↓ with opaque bottles and trays (because of wide variety of grades, colors and mixture with LDPE and PP)
PVC	Some	↓ (because of the cross-contamination with PET and PVC packages and labels)
LDPE	Some	↓ (because of low collection rate)
PP	Theoretically	– (because of low collection rate and presence of technology to recycle PP)
PS	Theoretically	↓ (because of the high cost of separation)

[27] This work doesn't consider energy recovery as a recycling process.

The following Figure shows the various steps characterizing the EoL of plastic waste.

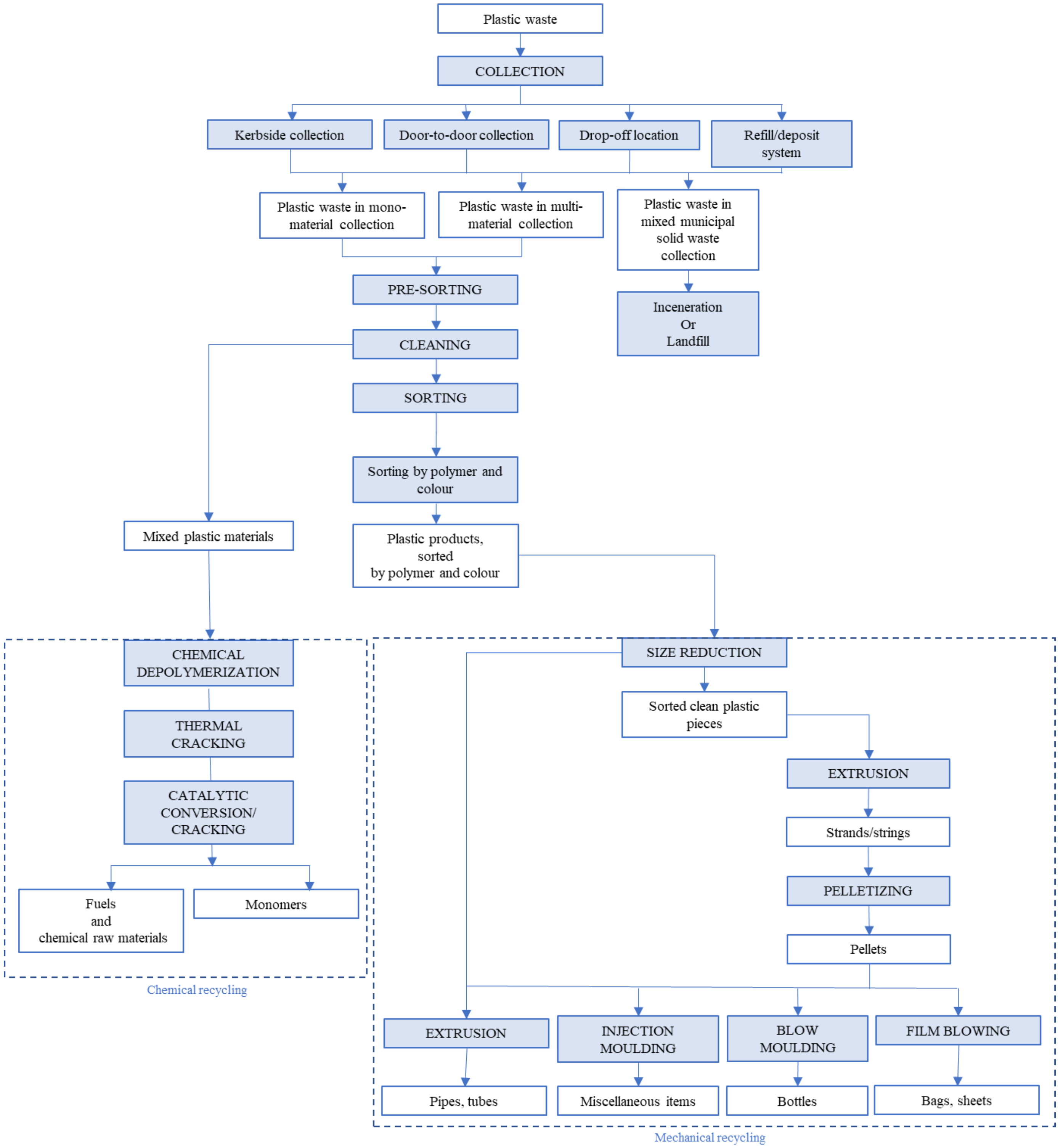


Fig. 19 End-of-life scenario for plastic waste treatment

According to the origin, plastic wastes may be completely different in composition and properties. Post-consumer plastic wastes[28] completely differ from pre-consumer/post-industrial plastic wastes[29]. Different is also the management of these wastes.

The layout for both type of waste streams, are shown below (Figures 20 and 21).

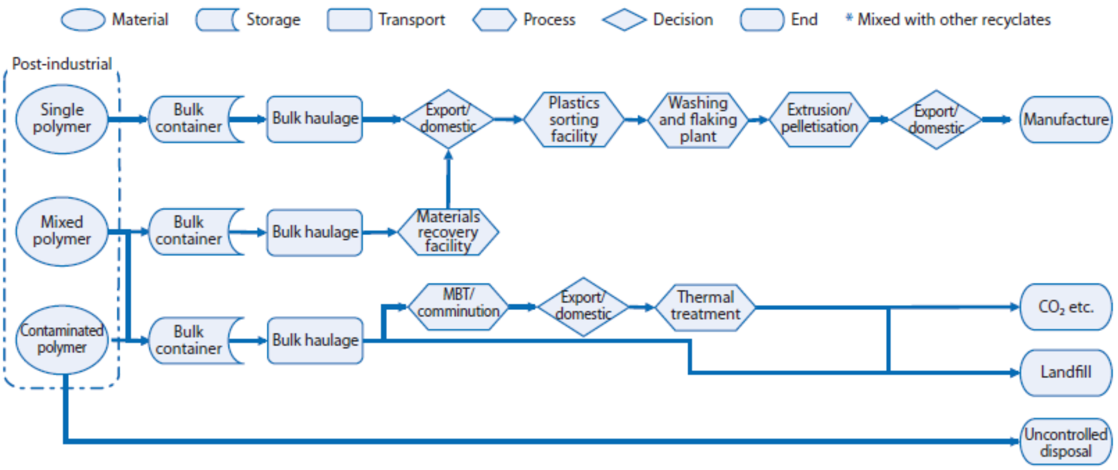
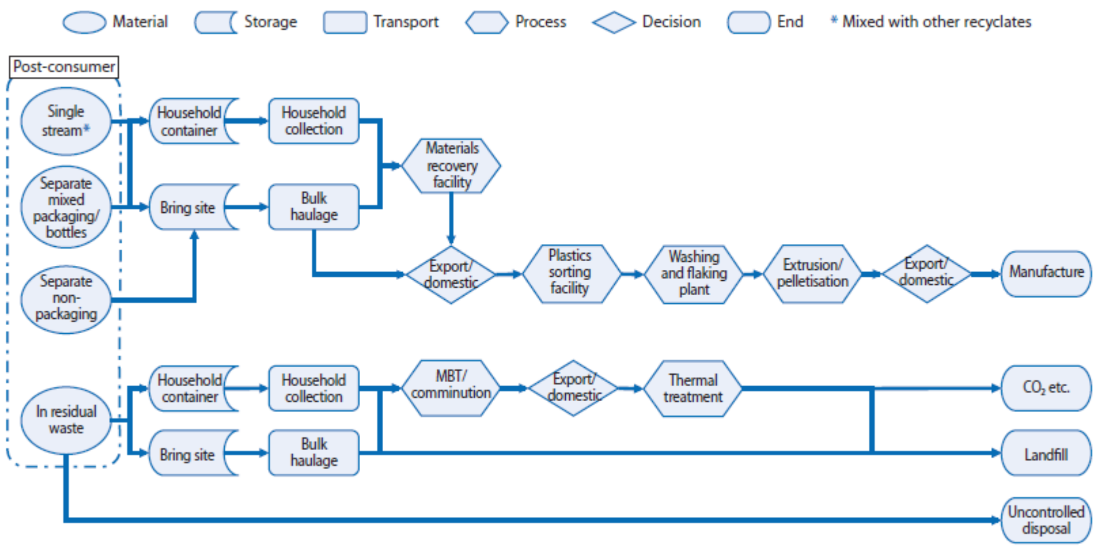


Fig. 20 Layout of pre-consumer plastic waste management – Source: OECD, 2018



nsumer plastic waste management – Source: OECD, 2018

[28] It refers to waste which have been sold or used, coming from residential, commercial and economic activity. It includes packaging and food packaging waste, as well as waste resulting from agriculture and construction sectors.
[29] It refers to waste resulting from manufacturing process which leaves the specific facility where it was generated. Scrap could be internally used, without leaving the plastics manufacturing plants. In this case, scraps are named as internal waste plastics (European Commission, 2014).

Additional implication is that plastic waste is strongly dependent on the life-span: some plastic products (especially the single use products) have a shelf life of less than one year, some others have a life-span of more than 15 years and some have a service life of 50 years or even more.
An article of Geyer et al. (2017) has combined plastic production data with product lifetime distributions for eight different industrial use sectors, or product categories, to model how long plastics are in use before they reach the end of their useful lifetimes and are discarded.

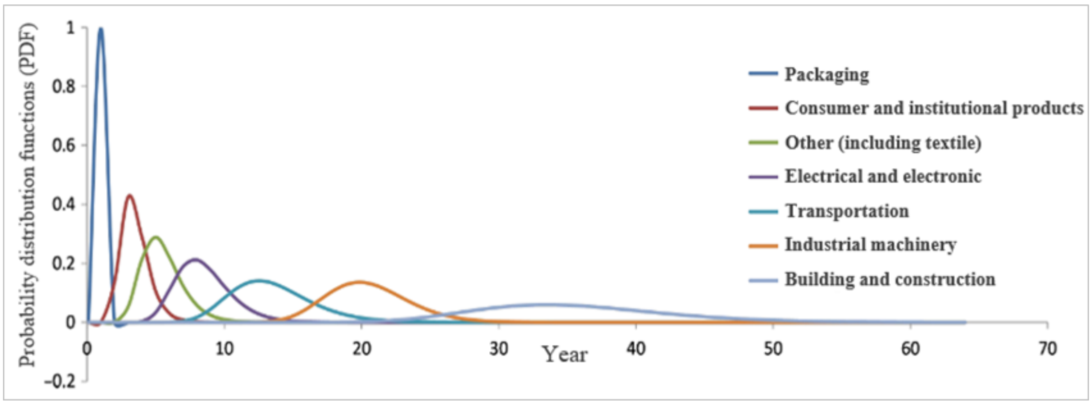


Fig. 22 Product lifetime distribution for the main plastics applications – Source: Geyer et al., 2017

Transferring this concept to plastics, the following graph (Figure 23) confirms that the biggest amount of waste results from packaging applications where single use packaging prevails to other type of packaging.

The following two figures shows the breakdown of the main polymers found in plastic waste stream and the correlation between generation and accumulation.

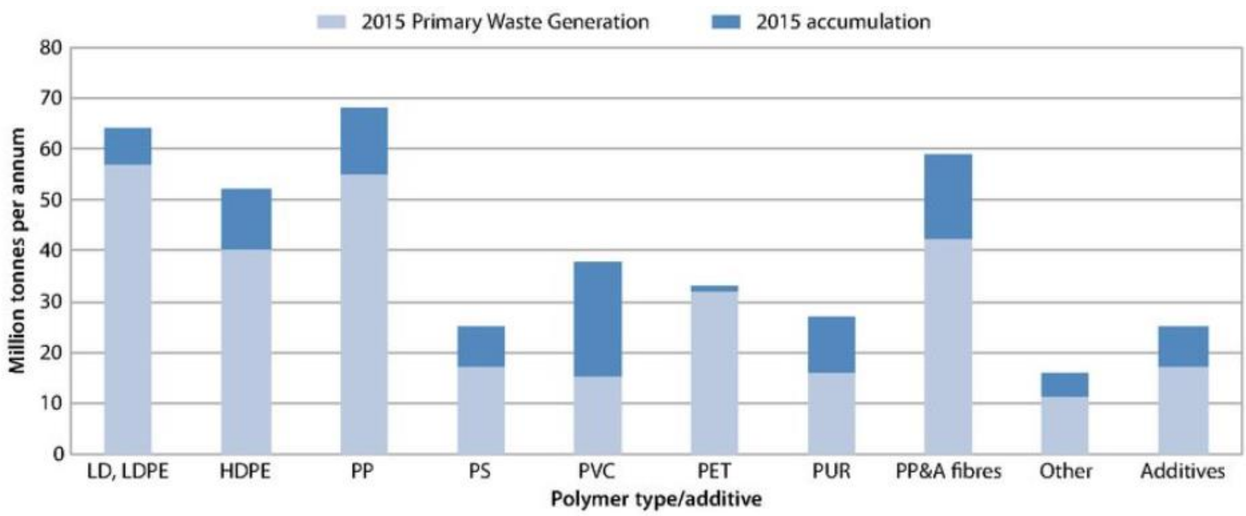


Fig. 23 Comparison of polymer production and diposal, 2015 – Source: Geyer et al., 2017

The global generation of plastic waste is estimated at 302 Mt (Geyer et al., 2017). The details, for sector of generation, are illustrated below.

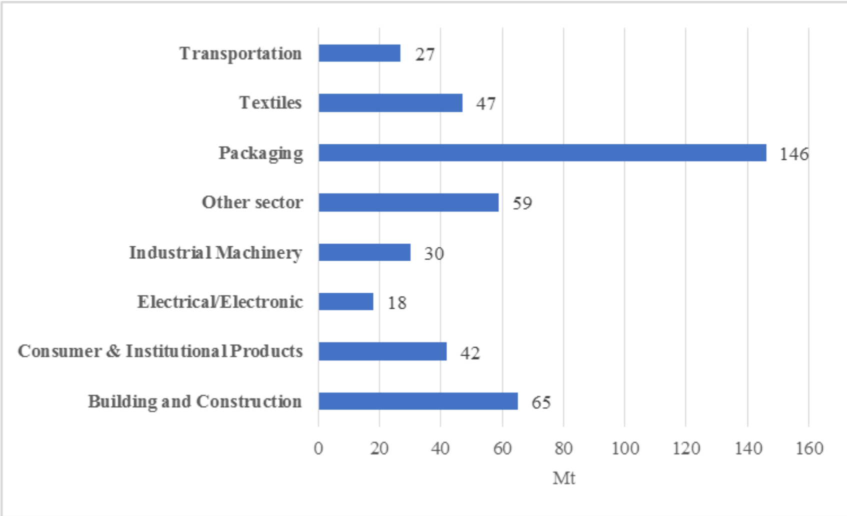
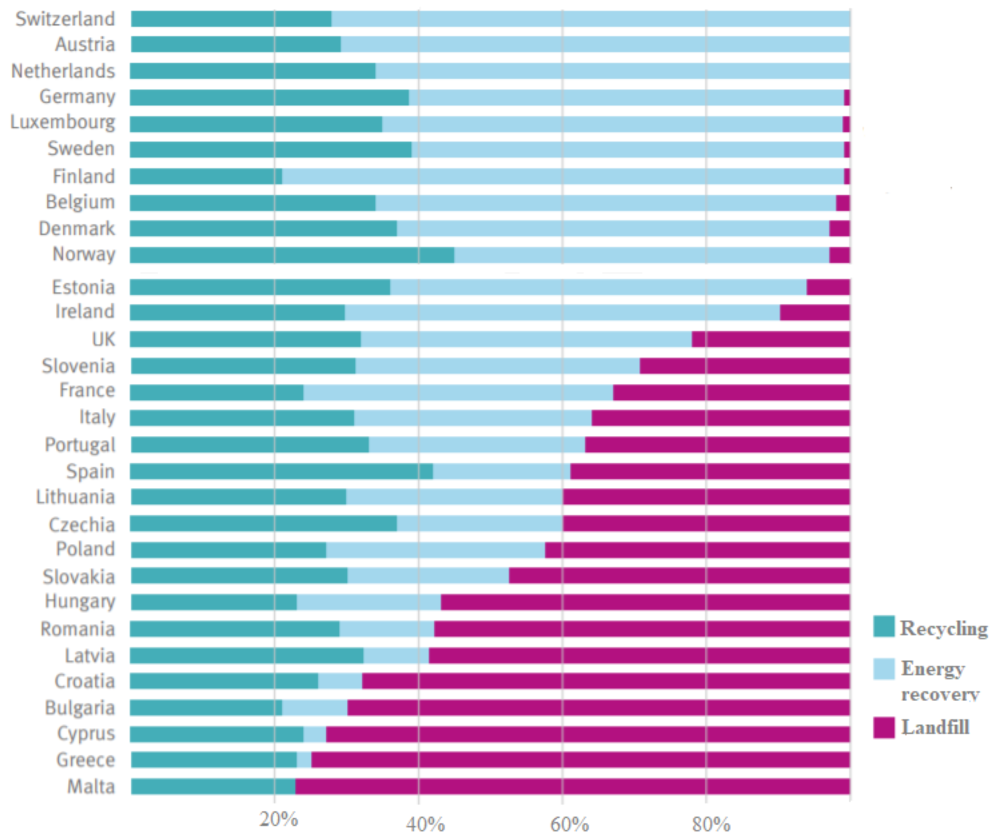


Fig. 24 Global plastic waste generation, 2015. Analysis by sector – Source: Geyer et al., 2017

The amount of post-consumer plastic waste disposed of by Europe[30] accounts for 27,1 Mt and 29,1 Mt respectively in 2016 and 2018[31]. In particular, in 2016 27,1Mt were collected and treated by official scheme, of which 31,1% was recycled, 41,6% incinerated and 27,3% landfilled (PlasticsEurope, 2018). In 2018, 32,5%, 42,6% and 24, 9% are respectively sent to recycling, incineration and landfilling facilities. The Figure below shows the 2018 performance for the management of post-consumer plastic waste.



[30] EU28+(NO, CH).
[31] No available data for the year 2017.

Fig. 25 Post-consumer plastic waste collection (C=collection) and treatment (R=Recycling, ER=Energy recovery, L=Landfill) in Europe (EU28+NO,CH), 2018 – Source: PlasticsEurope, 2019. Data have been elaborated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH.

No data on the breakdown of pre and post-consumer plastic waste by polymers has been found at EU level. In addition, pre-consumer plastic wastes are not well-recorded in Europe because of the lack of sharing information from the plastic conversion industry. However, a study performed by Ingham (2006), reveal that almost all the plastic production scrap is being re-fed into the plastic production system.

Considering the trade of plastic waste, the extra EU-28 imports amounted to approximately 144.000t in the year 2004 and rose to a maximum of 437.000t in 2010 and was stable for the period 2011 - 2015 (between 385 000 and 412.000t per year). The intra EU-28 trade started at approximately 865.000t in 2004 and increased to approximately 2,6Mt in 2017. The extra EU28 exports rose from 1.5Mt in 2004 to approximately 3,4Mt in 2010, an increase of 122% (EUROSTAT).

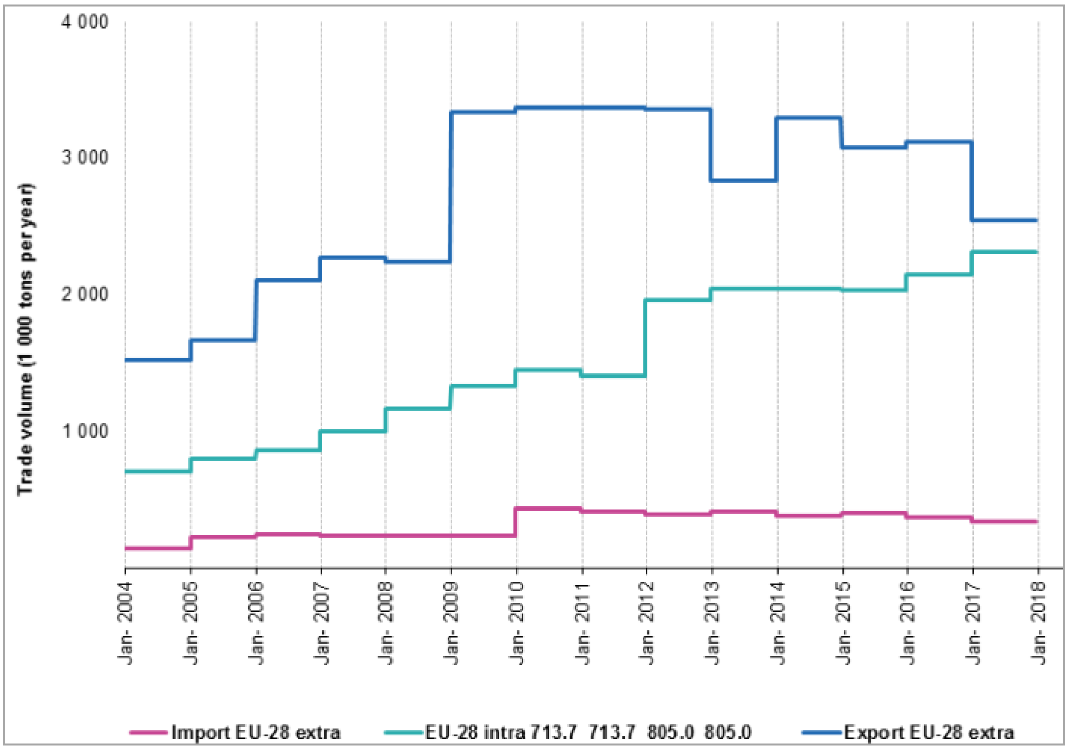


Fig. 26 Trade volume of import-export of plastic waste in Europe (EU28), January 2004-January 2019 – Source: EUROSTAT

According to the reference database for international trade in goods (COMEXT), the total export trade of EU plastic wastes accounted for around 300.000t in 2017 with preference to China. In 2013, China introduced a temporary restriction on waste imports that required significantly less contamination. In 2017, China also announced an import policy permanently banning the import of nonindustrial plastic waste (Brooks et al., 2018). Because of the Chinese waste import ban, the volumes of plastic waste material from EU-28 to China decreased by 95 % and to Hong Kong by 82 % compared with the previous year (See Figure 27).

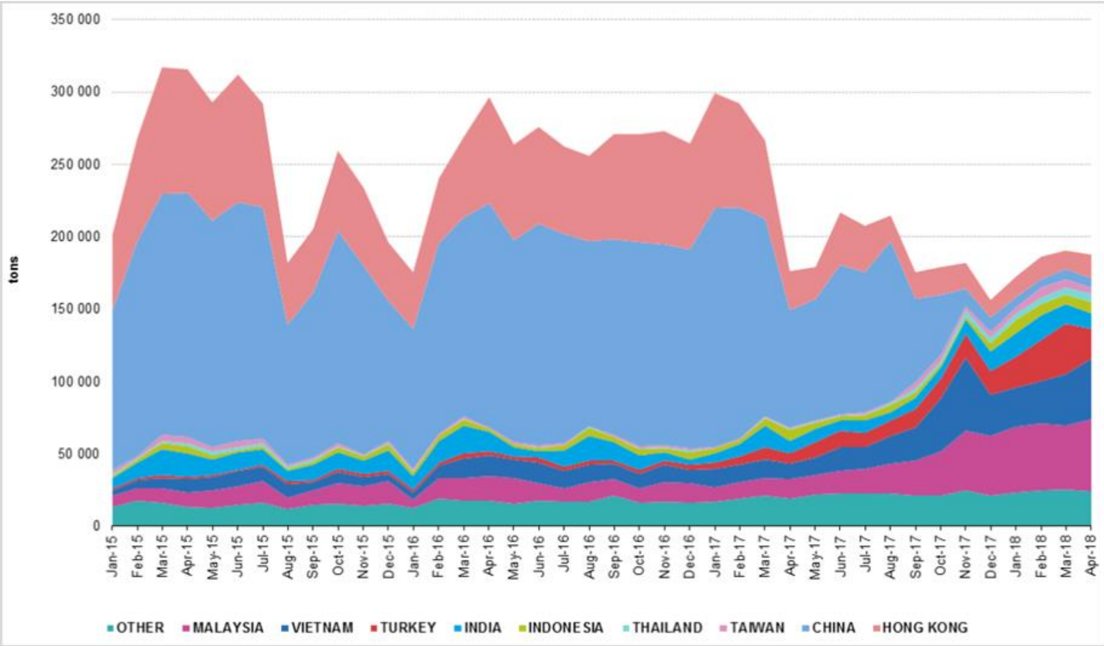


Fig. 27 Exports of plastic waste from Europe (EU28). Analysis for country of destination, January 2015 – April 2018 – Source: EUROSTAT

2.5.5 Remanufacturing industry

Reprocessing may be:

- **Downcycling** when materials are reprocessed in products of lesser quality or id different purpose than the original cycle.
- **Upcycling** when materials are used in a way that adds value to it, and that allows it to be repurposed, or downcycled or even upcycled again in the future

Recycled plastics meet around 10% of global demand for plastics (D’ambrières, 2019). The *European Strategy for plastics in a Circular Economy* reveals that only 10Mt of plastic waste are recycled in Europe (accounting for 5% of total plastic waste generated).

In Italy, 1,09 kilotons (kt) and 1,13kt of plastics are remanufactured in new products[32] respectively in 2017 and 2018. In 2017, the main applications have been packaging (27%), construction (26%), urban and interior furniture (15% and 9%), leisure and sport (6%), textile (4%), agriculture (3%) and other (10%).

2.6 Plastic intensity

Plastics can be used to manufacture the main body of products but at the same time, to package them. Depending on product type, plastic intensity can be very different.

An interesting research conducted by UNEP explores the industrial intensity of use of plastics for different type of goods. The study distinguishes:

- **Plastic-in-product**, referred to plastic directly used for manufacturing products.

[32] Federazione Gomma Plastica – Source:https://www.camera.it/application/xmanager/projects/leg18/attachments/upload_file_doc_acquisiti/pdfs/000/001/161/memoria_Federazione_Gomma_plastica.pdf

- **Plastic-in-packaging**, including plastic directly used for wrapping products and prepare them to be distributed or sold.
- **Plastic-in-supply-chain**, focused on plastic indirectly used by consumer goods businesses via their supply chain, without including it in the final product or packaging. It could be considered the tertiary packaging (as described in the Paragraph 3.1.2)

The study quantified the environmental impacts associated with plastic use using lifecycle analysis techniques. The natural capital valuation is then applied to convert physical impacts measured in terms of cubic metres of water used or tonnes of plastic entering the marine environment into a monetary value, expressing the damage caused to the environment and society[33].

The following graph (Figure 28) illustrates the estimated natural capital cost, as the sum of market and non-market cost resulting from the impact of plastics production and EoL management, where impacts assessment included greenhouse gas emission, pollutants (including chemical substances) and water consumption.

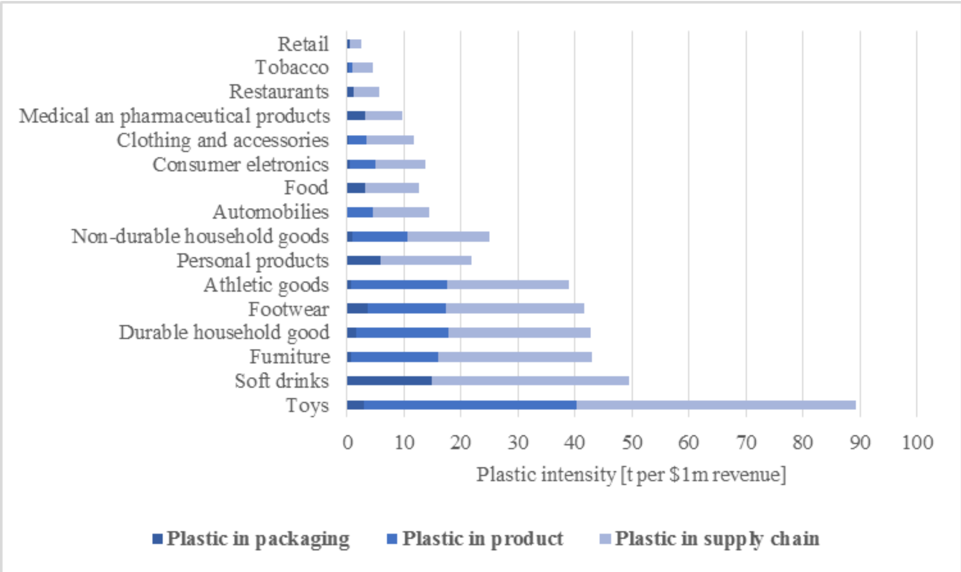


Fig. 28 Plastic intensity in Europe, 2012. Analysis by sector - Source: UNEP, 2014

As illustrated in the Figure 28, the toy sector has the highest total direct plastic intensity, while the retail sector has the lowest. Plastic-in-product is the larger proportion of total direct plastic intensity for all other sectors.

Plastic-in-packaging constitutes the main proportion of direct plastic intensity in the soft drinks, personal products, food, medical and pharmaceutical, restaurants and retail sectors. Sectors with the highest supply-chain-plastic intensity in relation to the total plastic intensity are the retail, restaurants, tobacco and food sectors.

2.7 Plastic impact

The study conducted by UNEP assesses the impact of plastics along the value chain by considering:

[33] The limitation of the study is that the impacts from manufacturing finished products and packaging and transporting and using those products and packaging is not considered.

- **Upstream**, referring to impacts generated from the extraction of raw materials to the manufacturing of plastic feedstock.
- **Downstream**, referring to impacts generated once the product has been discarded by the consumer[34].

Figure 29 illustrates the variation among sectors.

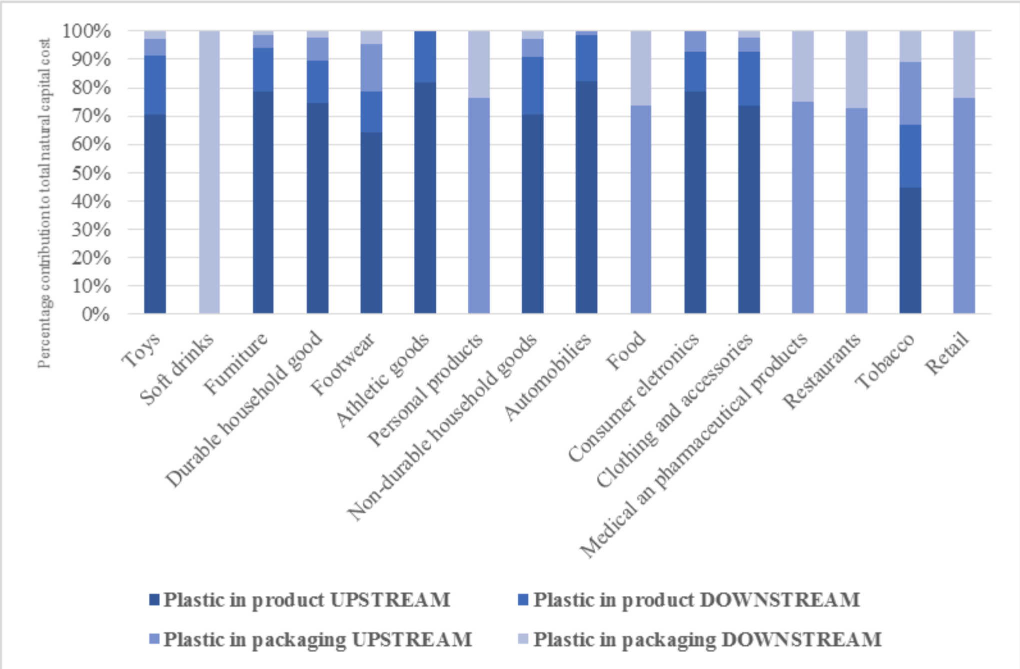


Fig. 29 Upstream and downstream impact split between product and packaging. Analysis by sector - Source: UNEP, 2014

The tobacco sector has the largest downstream impact. This is mainly due to the impact of plastic used in cigarette filters which are often littered after use. At the other end of the spectrum, the consumer electronics sector has the lowest downstream impact as a proportion of total impact mainly due to recycling initiatives in North America and Europe. In the end, across all consumer goods sectors, over 30% of the natural capital costs come from greenhouse gas emissions released upstream in the supply chain from the extraction of raw materials and manufacturing of plastic feedstock (UNEP, 2014).

Detailing the study on downstream, a study conducted by Bernardo et al. (2016) summarizes the environmental and economic life cycle analysis of plastic waste management options. The article shows the summary results of global warming potential (GWP) and total energy use (TEU) coming from the comparison between recycling, incineration and landfill of plastics; results shows recycling has the lowest impact, followed by landfill and incineration that has the highest impact.

A significant impact is given to the use of some additives that may release hazardous substances or degradation products during the entire product lifecycle. Since additives are not bound to the polymer matrix and because of their low molecular weight, these substances can leach out of the plastic polymer (Crompton 2007) into the surrounding environment, including into air, water, food or body tissues. Most effect are not known thus underestimating environmental and/or health risk.

34 Lack of data has led to study upstream impacts in a more complete and consistent way than downstream ones that, could be underestimated.

Lithner et al. (2011) studied this complex problem by conducting a comprehensive hazard ranking of the most widely used polymer types with global production volumes of >10.000 tonnes per year. A model for ranking the hazard of each polymer was developed by ranking the constituent monomer chemicals according to internationally agreed criteria for identifying physical, environment and health risks. The study regarding the hazard rankings has been performed by Galloway (2015) and some results are illustrated in table below (Table 8).

Tab. 8 List of polymers with the highest hazard scores – Source: Galloway, 2015

Polymer	Monomers/additives	Relative hazard score
PUR, as flexible foam	Propylene oxide Etylene oxide Toluene-diisocyanate Acrylonitrile Acrylamide Vynyl acetate	13.844
PAN with co-monomers	Acrylonitrile Acrylamide Vynil acetate	12.379
PVC, plasticised	Benzyl butyl phtalate (BBP) at 50wt%	10.551
PVC, unplasticised		10.001
PUR, as rigid foam	Propylene oxide 4,4'-methylenediphenyl diisocyanate (MDI) Cyclopentane	7.384
Epoxy resin	Bisphenol A Epichlorohydrin 4,4'-methylenedianaline	7.139
ABS	Styrene Acrolonitrile 1,3 Butadiene	6.552
SAN	Styrene Acrolonitrile	2.788
High impact PS	Styrene	1.628
LDPE	Ethylene	11
HDPE	Ethylene	11
PET	Terephthalic acid	4

PVA	Vynil acetate	1
PP	Propylene	1

An updated and detailed list is also arranged by the European Chemical Agency (ECHA) within the *Plastic additives initiatives* aimed to characterise the uses of plastic additives and the extent to which the additives may be released from plastic articles[35]. On the contrary of the table above, this table includes both dermal and inhalation releases where substances D, G and M have the highest potentials for release, while substances B, H, I and S have the lowest.

Tab. 9 List of potential release characterization for organic plastic additives – Source: ECHA

Substance name	Molecular weight (Da)	Vapour pressure (Pa)	Water solubility (mg/L)	log Kow (-)	Technical function	Polymeer Matrix	Conc. nn polymer (%)	Release indicator (dermal)	Release indicator (inhalation)
A	403.0	5.63E-04	4.85E-02	5.6	plasticiser	PVC (soft)	35	-2	-2
B	637.0	4.21E-21	2.19E-06	9.61	n.a.	PA	0.5	-7	-10
C	403.0	1.65E-11	1.26E-01	5.12	n.a.	n.a.	35	-2	-8
D	218.0	3.31E-01	5.80E+04	0.36	plasticiser	PVC (soft)	10	0	0
E	795.0	3.28E-22	6.60E-11	13.7	heat stabiliser	Polyolefin-I	2	-6	-9
F	553.0	1.39E-18	2.75E-04	7.79	antioxidant	Polyolefin-I	1	-5	-9
G	255.0	5.93E-16	2.70E+00	-2.28	flame retardant	PUR	30	0	-8
H	685.0	9.51E-14	4.68E-06	10	UV/light stabiliser	PMMA	1	-7	-9
I	593.0	1.06E-15	2.05E-10	14	Other stabiliser	Polyolefin-I	0.3	-7	-10
L	355.0	1.29E-03	1.14E-05	10.2	n.a.	n.a.	35	-4	-3
M	350.0	1.10E-11	2.30E+03	0.51	n.a.	n.a.	35	0	-9
N	214.0	9.48E-06	1.34E+05	0.19	flame retardant	ABS	25	-3	-4
O	414.0	1.95E-12	2.20E+00	3.57	nucleating agent	Polyolefin-I	2	-3	-9
P	451	9.83E-10	4.97E+01	2.9	UV/light stabiliser	Polyolefin-I	0.8	-3	-8
Q	224.0	6.28E-03	2.33E+02	2.51	Other stabiliser	PVC (soft)	2	-2	-2
R	254.0	2.32E-10	2.80E+03	-2.61	heat stabiliser	Polyolefin-I	2	-1	-5
S	733.0	1.07E-14	2.95E-12	15.1	antioxidant	Polyolefin-I	0.2	-7	-10
T	483.0	4.05E-06	4.78E-08	12	plasticiser	PVC (soft)	35	-4	-4

Considering specifically downstream impact, marine pollution is the most urgent and critical problem nowadays. The following study shows the average estimated decomposition times of typical marine debris items as results coming from the study conducted by the NH Hampshire Department of Environmental Services[36].

[35] ECHA – Source: https://echa.europa.eu/plastic-additives-initiative
[36] New Hampshire department of environmental service. Source: https://www.des.nh.gov/organization/divisions/water/wmb/coastal/trash/documents/marine_debris.pdf

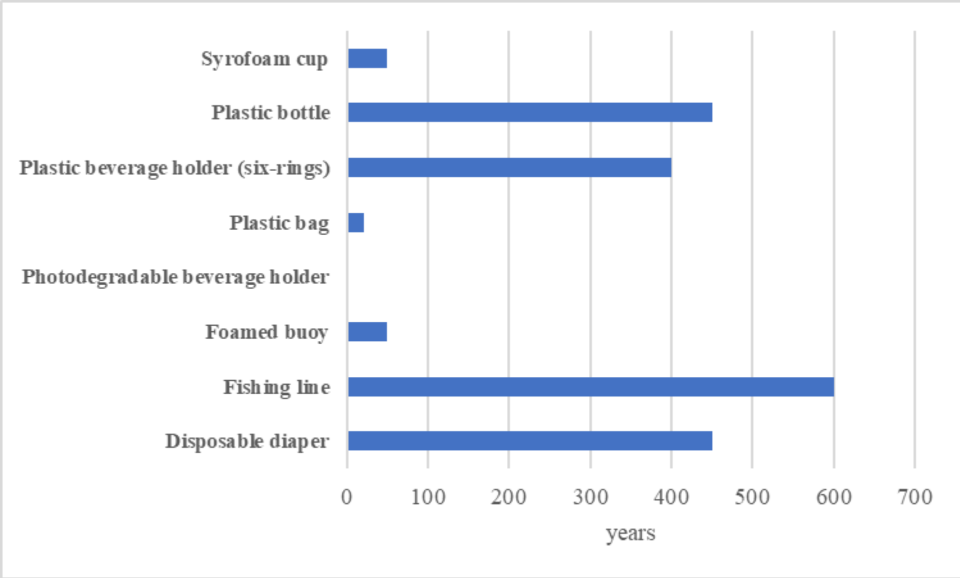


Fig. 30 Average estimated decomposition times of typical marine debris – Source: NH Hampshire Department of Environmental Services

As described in the Paragraph below (Paragraph 2.7.1), the lack of standardization in calculation method implicates uncertain estimation and undefinitions of the plastic impact assessment on environment, including marine environment.

2.7.1 Marine plastic pollution

As already mentioned, since plastics are affected by a low degradation rate, the impact of these materials in the environment is significant in the EoL phase. The problem of plastic pollution has become a major source of concern for governments, investors, and other stakeholders (Seltenrich, 2015). In recent times, plastic pollution has emerged as one of the most serious threats to ocean ecosystems (Chiba et al., 2018) and terrestrial ecosystems (Ng et al., 2018), although current understanding of the extent of the ecological impact of plastic pollution on the terrestrial environment is limited.
The several factors influencing the environmental impacts make difficult its estimation. Landon-Lane (2018) and Cole et al. (2011) refers that approximately 80% of plastic wastes are originated from land sources as consequences of incorrect disposal and mismanagement of waste on land. Illegal dumping, run-off, littering, and natural disasters are common pollutant sources (Carpenter and Wolverton, 2017; Dris et al., 2016). Proximity of plastic industries to rivers, oceans and other water bodies has been identified as a major enabler for plastic induced environmental pollution. Human activities on populated islands are also sources of plastic pollution (Monteiro et al., 2018; Miller et al., 2017), together with prevailing consumption model of several plastic items, which produce significant quantity of waste. Conversely, ocean activities such as shipping, and fisheries equally produce plastic debris which are transported for several distances to islands by wind and ocean currents. The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide (Derraik, 2002). Literature shows many articles dealing with the measurement of MPP in local context such as specific rivers, seas and beaches. Beaches have been identified as repositories for millions of plastic wastes (Lavers and Bond, 2017, Gregory, 2003) . Plastic debris can then enter the ocean by wind or tides (Jambeck et al., 2015). However, lack of harmonized information on waste generation, characterization, collection and disposal, unknown information about other sources of plastics into the ocean (Eg, illegal dumping, losses from fishing activity etc.) and import-export implications challenge the estimation of the amount of plastic debris reaching the marine environment. By linking worldwide data on

solid waste, population density and economic status, Jambeck et al. (2015) estimated the mass of land-based plastic waste generated by 192 costal populations (93% of global population) and entering the ocean in 2010. As illustrated in the map below (Figure 31), 275 Mt was generated in 2010, with 4.8 to 12.7 entering the ocean.

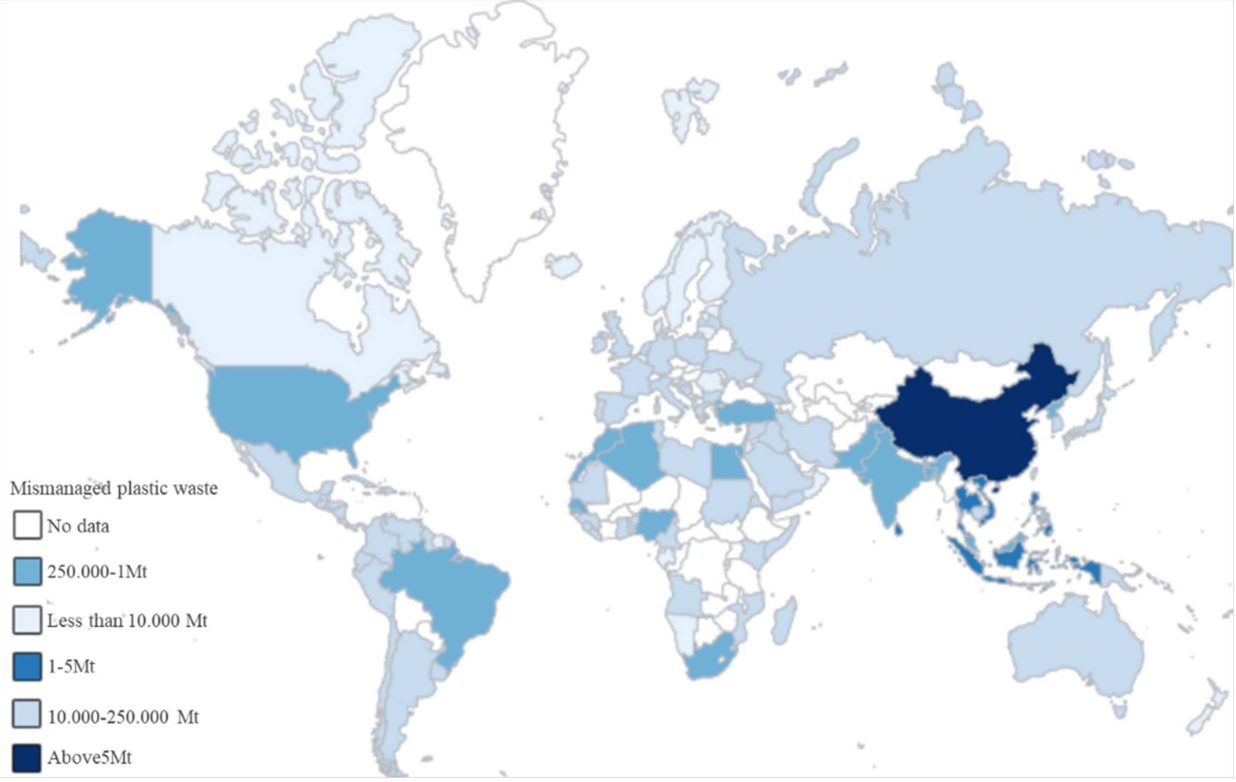


Fig. 31 Estimation of waste entering the ocean in 2010 for the top 20 countries (ranked by mass of mismanaged plastic waste) – Source: Jambeck et al., 2015

Investigation on EU MPP has revealed that about half of all marine litter items found on EU beaches is represented by Single Use Plastic (SUP) items. SUP has been defined within the Directive on SUP "*as a product that is made wholly or partly from plastic and that is not conceived, designed or placed on the market to accomplish, within its life-span, multiple trips or rotations by being returned to the producer for refill or reused for the same purpose for which it was conceived".* The 10 most found SUP items includes drink bottles with caps and lids, cigarette butts, cotton buds sticks, crisp packet/sweet wrapper, sanitary applications (sanitary towels, tampons etc.), plastic bags, cutlery, straws and stirrers, balloons and balloon sticks and food container (including food fast packaging). Another item is represented by plastic fishing gear accounting for 27% of marine litter items found on EU beaches that, summed to the litter given by SUPs, result a total litter of 70% (European Commission, 2018).
The MPP is increasing concern because of the presence of microscopic plastic debris, or microplastics (debris ≤1 mm in size), in aquatic, terrestrial and marine habitats that affects oceans, wildlife and, potentially, humans (Cole et al., 2011) and whom only sparse information are available (Galloway, 2015). The study carried out by Wright et a. (2013) provides an overview on marine invertebrates and their susceptibility to the physical impacts of microplastic uptake. Due to their small size. In fact, microplastics may be ingested by low trophic fauna, with uncertain consequences for the health of the organism. Other studies have been done on the impact of microplastics in the food chain, in cleaners and home detergents etc. but data have to be consolidated.

3 PLASTICS IN PACKAGING APPLICATION

3.1 Plastic packaging definition

The packaging definition is included in the Article 3 of the *Directive 94/62 CE on Packaging and Packaging Waste*. Packaging is defined *"as any material which is used to contain, protect, handle, deliver or present goods*" (European Parliament and Council, 1994). Items like glass bottles, plastic containers, aluminium cans, food wrappers, barrels, timber pallets and drums are all classified as packaging.

3.1.1 Packaging functionalities

Packaging covers a multitude of functions, such as:

- Protect the content from breakage, spoilage, loss, damage and theft, bumps and collisions as well as climatic conditions (E.g. temperature, humidity and solar radiation). In case of hazardous contents, the protection functionality aims to prevent any contamination or negative impact upon the environment.
- Load, transport, handle and store goods.
- Keep food fresh as longer as possible, thus preserving food integrity and saving food waste (in case of food packaging application) (Angellier-Coussy et al., 2013).
- Give information about the product and in particular about the ingredients, the hazardousness, the production, the storage, the usage, the disposal, the production etc. It also advises consumers about the correct disposal.
- Promote the instant recognition of the brand identification through packaging material, shape, size, colour and design (including colours, pictures, logos, slogans and other wording).
- Create value for sales process seeing as without packaging, many products, especially bulk products, cannot be sold to the customer (Pongracz, 1998).

Recent innovation on active and intelligent (A&I) materials has stimulated the packaging innovation by developing the so-called Modified Atmosphere Packaging (MAP) that is a food preservation technique whereby the composition of the atmosphere surrounding the food is different from the normal composition of air (APME, 2001). The interaction between food and its direct own atmosphere is done by monitoring oxidation, respiration rate, microbial growth, moisture migration; these processes are monitored through time–temperature indicators, ripeness indicators, biosensors and radio frequency identification (Dainelli et al., 2008; Restuccia et al., 2010).

3.1.2 Packaging categories

According to ISO 18601: 2013 (2013), packaging is often divided into three broad categories:

- **Primary (or Sale) packaging** that is the packaging depending on the product which forms a sales unit for the user (E.g. Plastic bottles, plastic food wrappers etc.)
- **Secondary (or Grouped) packaging** that is the packaging containing a certain number of sales units (E.g. plastic bottles carton, plastic cans wrappers)
- **Tertiary (or Transport) packaging** that is packaging used to group secondary packaging in order to allow transportation and distribution from the manufacturing industry to the retailers. (E.g. plastic pallets, bubble wrap)

Fast moving consumer goods (FMCGs) such as food, soft drinks, alcohol, toiletries, household products, are generally packaged by plastic materials and included in the first category.

While the tertiary packaging is generally characterized by a simple design, the primary and secondary packaging is heterogeneous and ends up in millions of households (Verghese and Lewis, 2007).

3.1.3 Packaging levels

The following additional terms are also frequently used to describe packaging levels:

• **Packaging constituent** is a packaging element that cannot be easily separated from the rest of the packaging (E.g. sealing layer in a laminated film)[37]

• **Packaging component** is part of packaging that can be separated by hand or by using simple physical means (E.g. packaging film)[38]

• **Packaging system**: the complete set of packaging for a given product, encompassing one or more of primary, secondary and transport tertiary packaging depending on the packed product[39].

3.1.4 Packaging types

The mechanical characterization of the packaging allows the distinction between:

- **Flexible packaging** characterized by elastic deformation.
- **Rigid packaging** where the deformation is elastic.

In the plastic field, flexible packaging is represented by film used to form bag or pouch. The main polymers used to produce films include PP, PE, nylon and PS. Rigid plastic packaging are made of PC, PVC, PS reinforced with fiberglass and Methil PMMA (Orzolek, 2017). The design innovation characterizing flexible packaging and the technological limitation of rigid ones is fostering the market growth for plastic film.

The packaging durability, and consequently usability, dictates the distinction between:

- **Single-use / One way packaging**
- **Multiple-uses / Reusable or returnable packaging**

Single use plastic packaging refers to items intended to be used only once before they are thrown away for disposal. These include grocery bags, food packaging (especially FMCGs), bottles, straws, containers, cups and cutlery. Reusable or returnable packaging is mainly a domain within beverage packaging. Some smaller reuse systems for food and detergents are spreading in small independent retailer's or green shops. Reusable pallets, buckets and crates are becoming more common in shipping, handling and transportation. Furthermore, reusable packaging model are applied in the e-commerce sector.

3.2 Fossil_based plastic materials in packaging applications

Packaging could be made of one or more materials, and characterized by specific shapes and texture, scientifically designed to suit the product being packaged, to suit the hazards of the transit journey, to maximise the shelf life of the product and to ultimately positively influence the consumer purchase decision. Plastics are widely used to manufacture packaging. Packaging represents 26% of the total volume of plastics used (Ellen MacArthur Foundation, 2017). Indeed, around 60% of all plastic packaging is used for food and

[37] More information are available at EN 1342713, ISO/CD 18601.
[38] More information are available at EN 13427, ISO/CD 18601.
[39] More information are available at ISO/CD 18601.

beverages, while the rest covers non-food applications, such as healthcare, cosmetics, consumer, household, apparel, and shipment packaging.

PE, PP, PET, PVC, PS are the main polymers used in packaging sector. Details about the polymers' applications are shown in the Figure below.

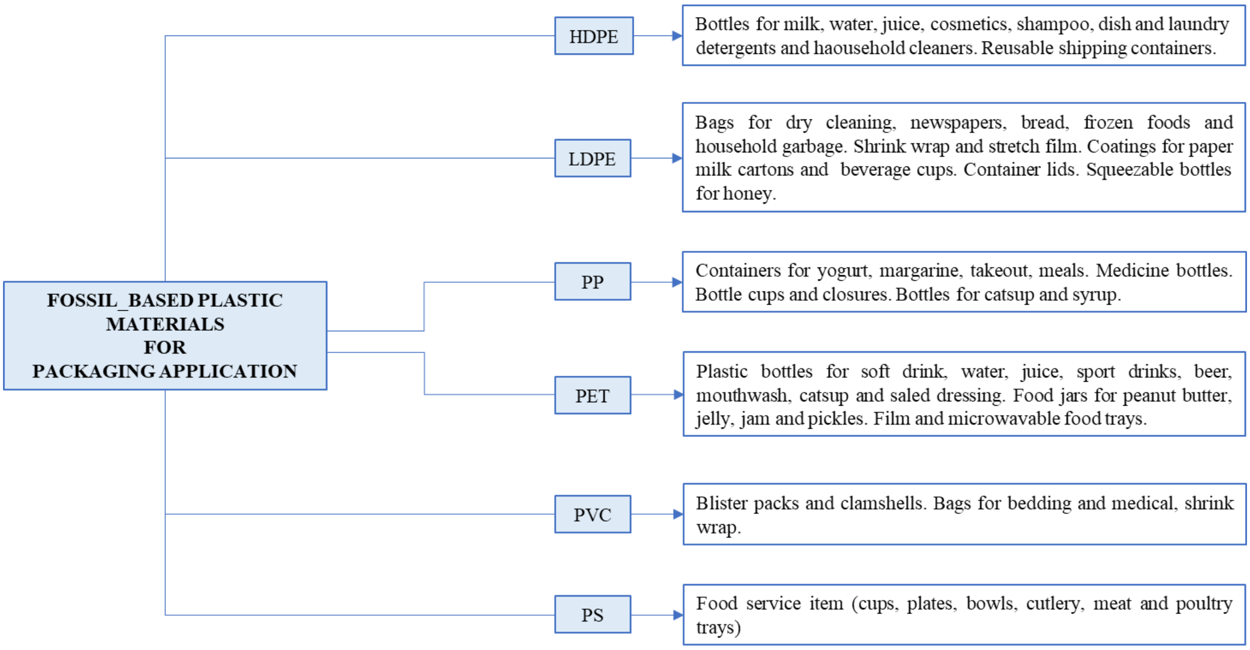


Fig. 32 Plastic packaging applications. Analysis by polymer type

Another type is the multi-layer package, which combine different layer of paper or board, and aluminium foil or plastics into one thin packaging film. Composite packaging are not the central point of this study.

3.3 Plastic packaging value chain

Packaging is managed continuously at several level of the supply chain:

- **during the production phase**, when scraps of manufacturing are generated
- **at the distribution stage** when grouped products are unwrapped and prepared to be worked or resold
- **at the final consumer**, when the primary packaging is removed from the product.

At the utilization phase, different levels of packaging utilization can be identified:

- **Private use**, at domestic level
- **Commercial or retailer use**, for wrapping goods which are intended to be sold
- **Industrial or business use**, where packaging is adopted for logistic or productive purposes.

Therefore, manufacturers of packaging materials and packaging machinery as well as households, industrial or commercial users and retailers but also waste operators are the main stakeholders involved in the plastic packaging value chain (See Figure 33). Since a huge number of additives (plasticizers, flame retardants, antioxidants, acid scavengers, light and heat stabilizers, lubricants, pigments, antistatic agents, slip compounds and thermal stabilizers) are used in manufacturing plastic resins for packaging application, the compounding industry is highly dependent on plastic packaging market (Hahladakis et al., 2018).

As mentioned above, packaging can be designed for single-use or multiple uses. According to this scope, the plastic packaging value chain may vary:

- If the packaging is designed to be reused, a returnable system is implemented.
- If the packaging material is used ones, legislative requirements demand that the waste is collected and recycled for packaging material reprocessing (**Upcycling recycling**) or other applications (**Downcycling recycling**) (Steinhilper et al., 1997).

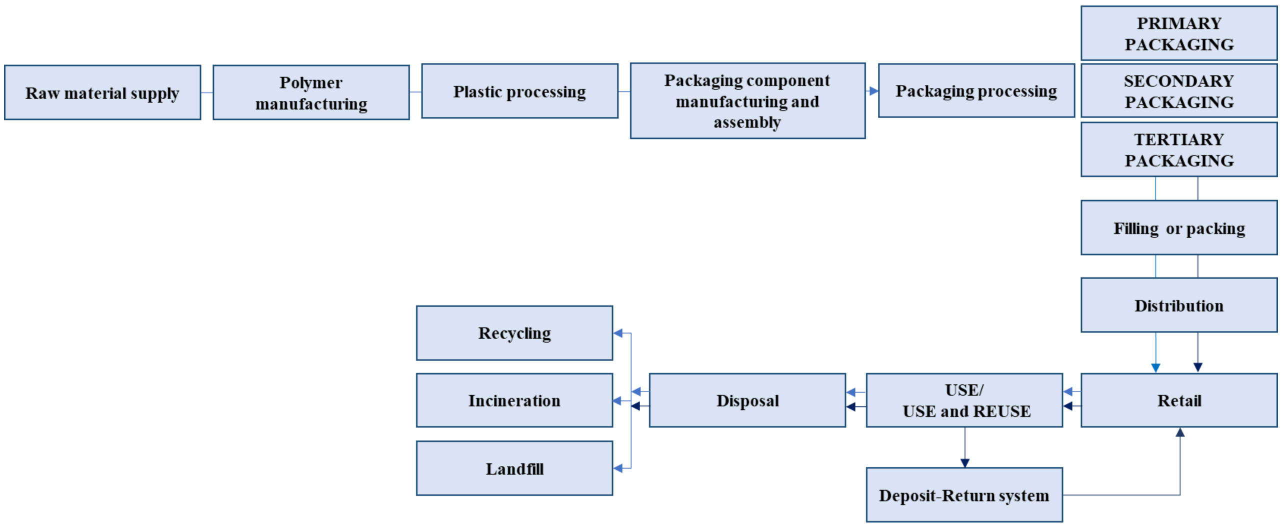


Fig. 33 Plastic packaging value chain. Simplified version

Verghese and Lewis (2007) has provided a value chain that considers all packaging used to transport the resources needed to manufacture, commercialize, use and dispose other packaging (See Figure 34).

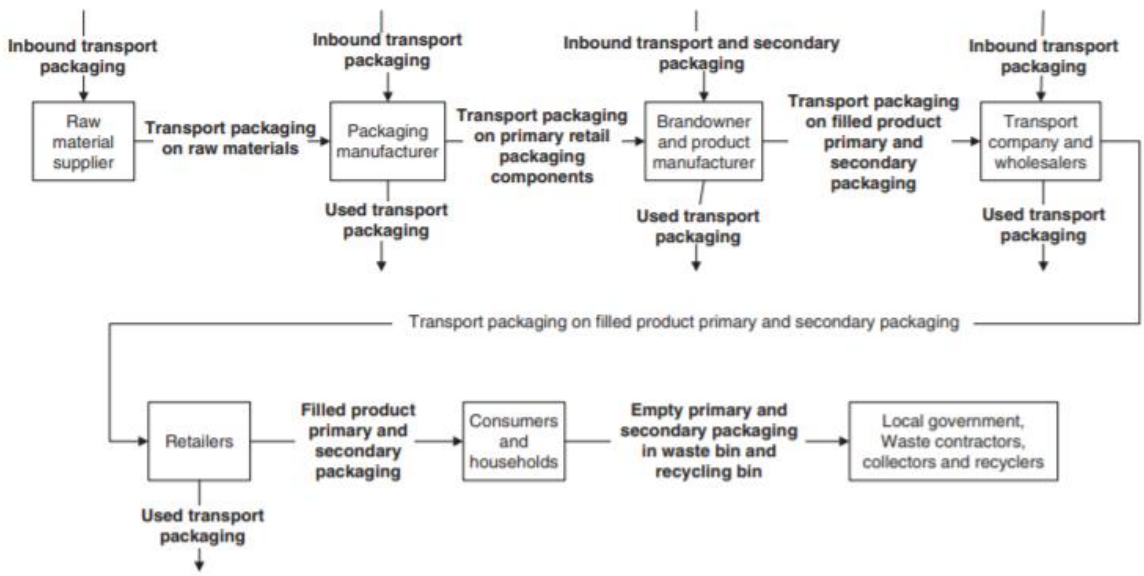


Fig. 34 Plastic packaging value chain – Source: Varghese and Lewis, 2007

3.3.1 Plastic packaging industry

Since packaging is an integral part of the food and drink, personal care, pharmaceuticals, chemicals industries etc., packaging industry is intertwined with all type of industries.
At global level, the plastic packaging market was valued at close to USD 198 billion in 2017, where USD 66,7 billion were referred to rigid plastic packaging and USD 131,2 billion to flexible segment. Trucost, a consulting group that tabulates the environmental impact of business practices in dollar terms, conducted a study on behalf of the UNEP in 2014. The study estimates that the global food and soft drinks sectors consume over 32 Mt of plastic resin for use in packaging each year, over half of this occurring in Europe and North America (UNEP, 2014). Bottles covered the highest revenue in 2017, followed by bags and wraps and films.

The 10 largest plastic packaging companies in the word are:

1) Amcor (Switzerland)
2) Apla-Werke (Austria)
3) Coveris Holdings S.A (USA)
4) Sealed Air Corporation (USA)
5) Rpc Group (UK)
6) Mondi Group (UK)
7) Aptar Group SAS (France)
8) Constantia Flexible holding (Austria)
9) Klockner Pentaplast (Germany)
10) Papier Mettler (Germany)

where 8 out 10 are located in Europe.

Packaging applications are the largest conversion sector for the EU plastic industry, accounting for 39,7% and 39,9 % of the total plastics demand in 2017 and 2018 (PlasticsEurope, 2019). In particular, the manufacturing of plastic packaging products (NACE C222) employed some extra 1.300.000 persons, distributed over 55 thousand firms, of which only 753 are not SMEs. About 20% of persons are employed in the manufacturing of plastic packaging goods. In terms of added value, the sector generated 64 billion EUR, accounting for 3,7% of total EU manufacturing[40].
In Italy, 1.301 companies work on plastic packaging manufacturing[41]. The national plastic packaging market reflects the manufacturing one since goods must be packaged for distribution and commercialization. In 2018, the sector generated an added value of 15 billion EUR with 2.292 kt of plastic packaging placed on the market in the same year (Fondazione per lo sviluppo sostenibile, 2019). Since in 2017 the commercialization registered an amount of 2.271kt, the 2018 plastic packaging market has seen a rapid growth ((Fondazione per lo sviluppo sostenibile, 2019). According to the packaging type, 56% of packaging placed on the market were rigid while the remaining were flexible packaging (Fondazione per lo sviluppo sostenibile, 2019). The comparative analysis laid down on 2017 and 2018 trends allows to identify factors characterizing the current landscape. A sensitive increase has been registered for thermoformed trays (that are mainly exported in Northern Europe) and bottles market (Istituto Italiano Imballaggio, 2018). Regarding the relation with the entire packaging market, the national plastic packaging covers about 18% of the total packaging demand and

[40] Source: Eurostat, Structural Business Statistic.
[41] Data are provided by the Chamber of Commerce.

46% of the total packaging turnover[42]. The same situation is reported for the year 2017 where the revenue coming from the commercialization of plastic packaging is the highest.

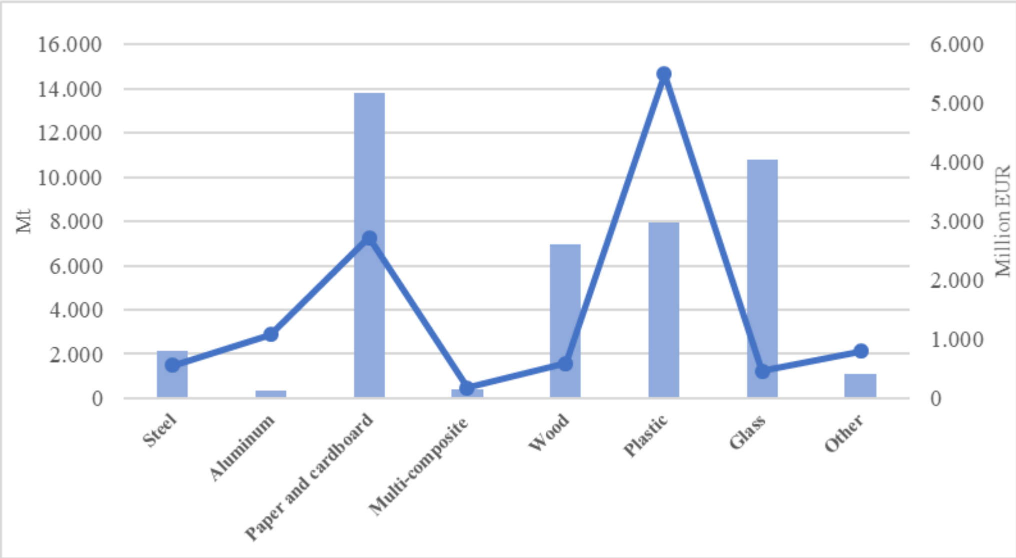


Fig. 35 Production and value of packaging in Italy, 2017. Analysis by material type – Source: Istituto Italiano Imballaggio, 2018

3.3.2 Plastic packaging waste management

Owing to the short lifespan (especially for single-use packaging), packaging is immediately converted to waste[43]. Packaging constitutes to one third of all collected municipal waste by weight, and half by volume. Packaging waste can arise from a wide range of sources including supermarkets, wholesale and retail stores, manufacturing industries, households, hotels, hospitals, restaurants and transport companies. It follows that packaging becomes waste at different level of the packaging value chain:

- **at the final use stage** (including consumption) when the primary packaging is removed from the product
- **at the distribution stage** when individual products are removed from secondary transport packaging
- **at the retail stage** when packaging is used to group products

The lack of uniform and harmonized data doesn't allow to know the total amount of packaging placed on the market and disposed of. Available data refers to packaging disposed of by the consumers as output of the residential activity. As illustrated in the figure below showing the breakdown of packaging waste composition by material, (Figure 36), plastic is one of the most widely used materials found in waste stream.

[42] Data are detected from the Economic Packaging Forum.
[43] In contrast to other waste statistics, the term 'packaging waste generated' means not the amount of 'packaging collected', but all 'packaging placed on the market'. This definition is based on the fact that packaging is most of the time thought as a single-use object, with the only purpose to wrap the final product and that can be thrown away.

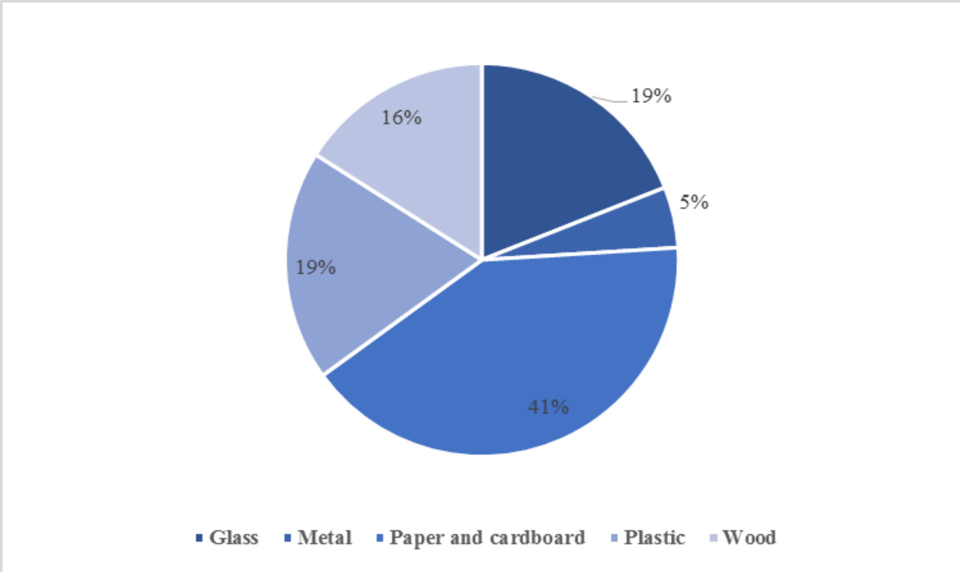


Fig. 36 Packaging waste composition in Europe (EU-28), 2016[44]. – Source: EUROSTAT

According to the level of generation, waste are generally categorized as:

- **Pre-consumer waste**
- **Post-consumer waste**

Pre-consumer waste are generated by industries, business and retailers. Industries and small businesses and retailers have to make use of private waste collection companies to discard their plastic packaging waste (PPW), although small businesses often also make use of municipal collection systems.

According to the EU List of Wastes[45] (that provides a framework for the collection of official statistics on plastic waste streams), the following Table (Tab 10) shows an overview of categories for type of packaging waste.

Tab. 10 List of packaging waste. Analysis by European waste code – Source: European Commission, 2000

Type of packaging waste	EU Waste code (EWC)
Paper and card board packaging	**150101**
Plastic packaging	**150102**
Wooden packaging	**150103**
Metallic packaging	**150104**
Composite packaging	**150105**
Mixed packaging	**150106**
Glass packaging	**150107**
Textile packaging	**150109**
Packaging containing residues of or contaminated by hazardous substances	**150110**
Metallic packaging containing a hazardous solid porous matrix	**150111**

[44] No available data for the year 2017.
[45] European Parliament and of the Council. Source: Commission Decision 2000/532/EC - https://publications.europa.eu/en/publication-detail/-/publication/239a2785-9115-4e06-adae-66c8e08a5a42

Since this study is focused on plastics, the packaging waste stream under investigation is the plastic packaging as categorized by the EWCs 150102 referring to post-consumer PPW that are generally generated by households. As aforementioned, a smallest amount of waste coming from economic and commercial activities can be collected through the public collection service. These wastes are called Assimilated/Similar waste and codified with the EWC 200139. Owing to the treatments done in the MRFs, waste may change the EWC. In case of plastics, any EWC may become the EWC 191206, categorized as plastic waste generated within a waste treatment plant.

The EU PPW accounted for 61% of total plastic post-consumer waste (17,8 Mt) in 2018 (PlasticsEurope, 2019).

Post-consumer waste can be collected in different way, such as:

- **Kerbside collection** (separated as single stream or mixed with plastic packaging, or dry packaging or residual waste). It is widespread in Austria, Belgium, Germany, Italy, Portugal, Spain (Watckins et al., 2012).
- **Bring-site collection.** It is widespread in Sweden, the Netherland, UK, Portugal, Ireland, Finland (Watkins et al., 2012).
- **Deposit-refund system (DRS)**, for reusable packaging, mainly widespread in Germany and Finland.

After the collection, PPWs are transported to the MRFs. Once the plastic waste reaches deposits or recycling facilities, the sorting activity is performed. PPWs are firstly separated from other materials and then sorted to obtain different polymers and colors. Manual sorting as well as automated sorting processes exist[46]. Separation process are based on spectrophotometric density and magnetic properties. Eddy current separation is used to sort non-ferromagnetic objects. X-rays are also used for sorting very dirty bottles or those having large labels. Near infra-red rays (NIR) is a color-based sorting technology. NIR automatic sorting machines is able to sort the major polymer groups with the exception of black plastics present (mainly PP and PET trays and tubs), which the NIR sorting systems could not identify (WRAP, 2011). Since polymers are characterized by different densities, the sink float density separation process separates polymers by density (Gent et al., 2009). Another important step is represented by the contamination removal that may be macro-physical or chemical. Cleaning process is used to remove oil, solvents (especially water_based glue), paint, or detergents absorbed by plastic products (Villaneuva and Eder, 2014). The residues are sent to the Waste-to-energy (WTE) treatment and/or landfill (WRAP, 2009).

[46] To facilitate the visual identification of plastic types during manual separation, major plastic components (container, caps, and lids) should carry a material identifier. Material identification is also of use when recycling industrial waste either internally or externally or where clean waste streams, components or packaging are being recycled from industrial / commercial sources where washing /separation is unnecessary. In Europe, material identification is promoted in the Commission Decision 97/129/EC. Technical norms (ISO 1043-1, ISO 1043-2, ISO 1043-3 and ISO 1043-4) also refer to the identification of the plastics, provided by the symbols and abbreviated terms. It takes inspiration from the codification established by the American Society of the Plastics Industry (SPI). SPI codes are mandatory in US. Even if it is based on voluntary approach, SPI codification is widely used in Europe.

Fig a. SPI codes – Source: Polychem Usa. Raw materials for the plastic industry

As shown in the figure below, the recycling plants treat those products characterized by a certain polymeric composition as demanded by the market.

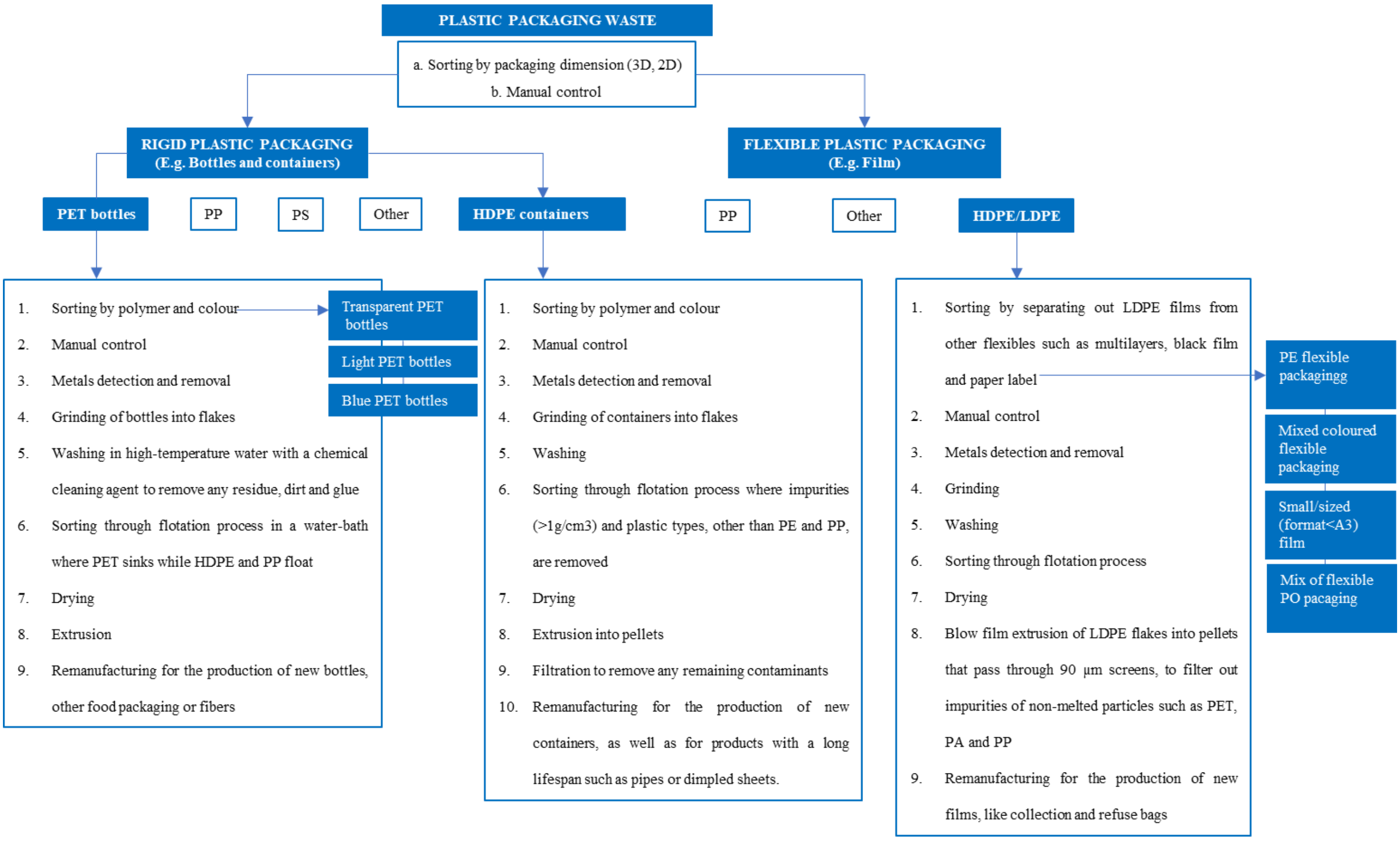


Fig. 37 Description of the most common plastic packaging recycling processes

The sorted plastics are then baled and transported to the recycling industry for reprocessing (WRAP, 2009) obtaining pellets, agglomerates, regrind, flakes and other recycles depending on the type of resin. In some cases, the sorting and recycling processes can be performed by the same plant.

In Europe[47], 16,7 Mt and 17,8 Mt of PPW were collected through official schemes in 2016 and 2018 (PlasticsEurope, 2018; 2019). For the amount collected in 2018, 42% was sent for recycling while the remaining was landfilled (18,5%) and incinerated for energy recovery (39,5%) (PlasticsEurope, 2019).

[47] EU28(+NO/CH).

The Figure below shows the details of EoL treatments for PPW collected in 2018.

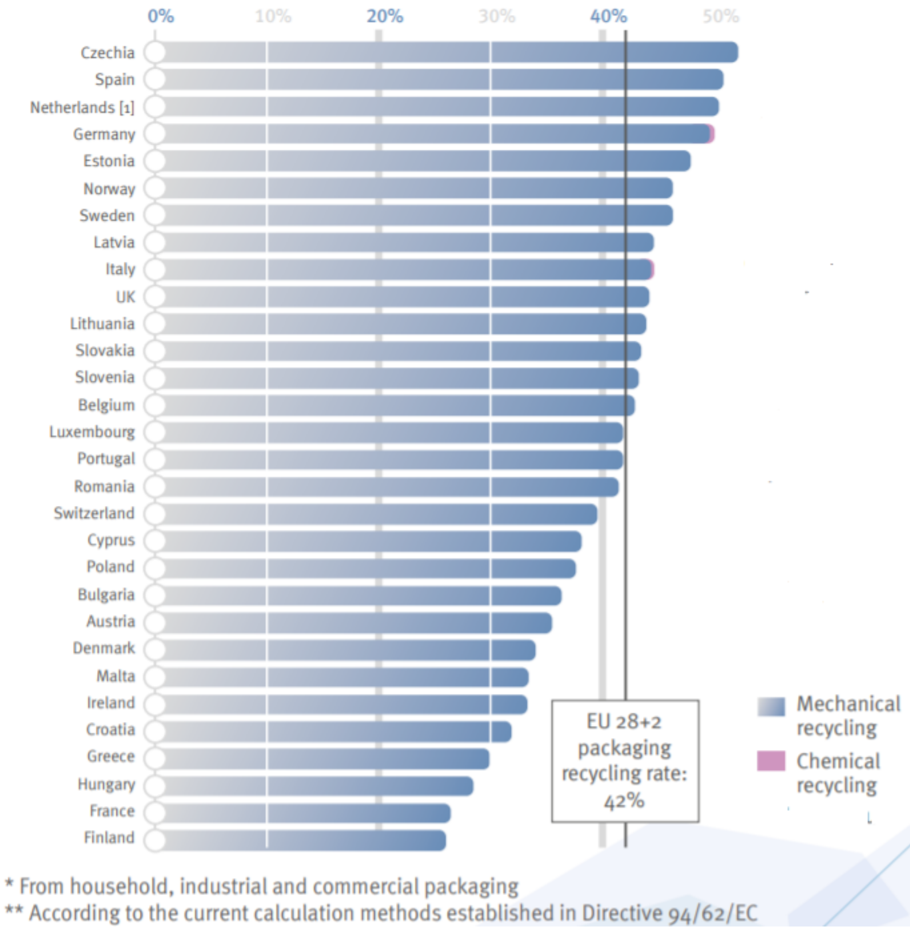


Fig. 38 Post-consumer plastic packaging waste collection (C=collection) and treatment (R=Recycling, ER=Energy recovery, L=Landfill) in Europe (EU28+NO,CH), 2018 – Source: PlasticsEurope, 2019. Data have been elaborated by PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH.

In Italy, 1.074kt and 1.220kt were collected in 2017 and 2018. The amount sent to recycling was 950kt in 2017 and 1.020kt in 2018. Regarding the management, COREPLA treated 587kt in 2017; the remaining was processed by the Independent consortia. The following year has registered a similar trend: 644kt was managed by the COREPLA and the remaining (376kt) was treated by the Independent consortia (See Figure 39) (Fondazione per lo sviluppo sostenibile, 2019).

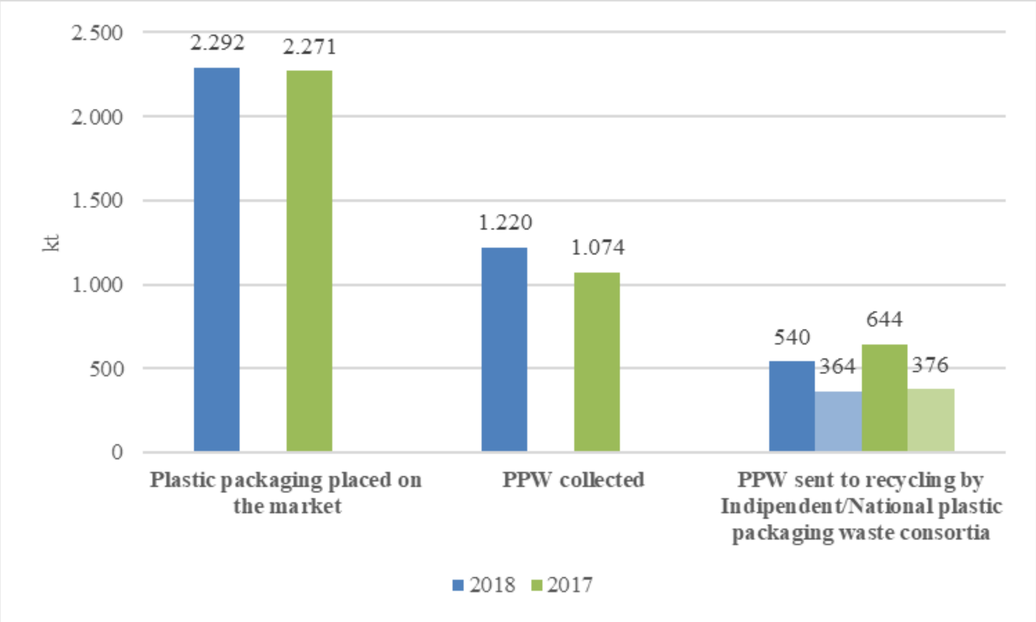


Fig. 39 Status of Plastic packaging in Italy, 2017 and 2018 – Source: Fondazione per lo sviluppo sostenibile, 2019

The secondary raw materials are converted into products, in the same way primary plastic raw materials are converted into products (NewInnoNet, 2015). Depending on technical (polymers' type, colours, additives) and legal requirements as well as market demands, PCR plastics can be remanufactured in a closed or open loop. The current highest demand of recycles is covered by rPET, rLDPE and rHDPE (Deloitte Sustainability, 2017). HDPE and PET generally turned at its original functions in a closed-loop recycling (CLR). If recycling deals with highly purified plastics, the added value of recycling is pursued. This is particularly highlighted by clear PET packaging that is generally remanufactured into recycled food packaging (such as cups and trays) while coloured PET is segregated and used to make strapping (WRAP, 2009). Films (made of LDPE) are not remanufactured at the original packaging application. Mixed plastics are generally used to make furniture.

In Italy, the first study on secondary plastics was performed by EcoCerved and published by Fondazione per lo Sviluppo Sostenibile in collaboration with FiseUnicircular in 2019. Being not waste, the communication of secondary plastics is not mandatory; therefore, data may not be robust. In 2017, 1.126kt entered the recycling plants (about 37% were sourced from PPW streams). The amount of secondary plastics generated has been estimated at 895.849t[48] (Fondazione per lo Sviluppo Sostenibile, 2019).

Remanufacturing or effectively reprocessing refers to waste fractions that have been actually and efficiently recycled. This should include high-quality recycling processes, where materials are recycled comprehensively in conditions respecting EU environmental and social standards (Eurometaux, 2016). No official data are available on the amount of plastics effectively remanufactured in new products. The EU initiative *Monitoring Recyclates for Europe* (MORE) is currently undergoing testing to collect data on the volumes of recycled polymers used by plastics converting companies[49] .

Municipal waste (waste from households and similar, also called post-consumer) and special (waste from industrial/commercial activities, also called pre-consumer) waste are managed in different ways. While

[48] Data are sourced from Modello Unico Ambientale 2018 and elaborated by CERVED GROUP.
[49] Monitoring Recylates for Europe – Source: http://moreplatform.eu/

special wastes are managed by independent consortia or private companies, municipal waste (and in particular packaging waste) management is regulated by the national waste consortia. Further information is included in the paragraphs below.

3.4 Plastic packaging waste system

Each EU MS has its own waste management system in accordance to the national law. As laid down by the article 182bis of Legislative Decree 152/06, the Italian self-sufficiency of municipal waste management has led the regions to guarantee, as much as possible, the plastic waste treatment internally (Italian government, 2006). This principle has catalysed the launch of a framework of waste operators, consortia and enterprises. Since the legislative frameworks provides measures for municipal waste and post-consumer plastic waste mainly involves municipal PPW, the system appears more organized than the system for special ones where a competitive market prevails.

3.4.1 Plastic packaging compliance scheme

Packaging is characterized by a well-defined waste management system. In fact, packaging, including plastic packaging, are collected by official waste scheme as pushed by the statutory producer responsibility regime. The so-called EPR has been introduced through the legislation[50] to internalize EoL costs into the products' price. According to the OECD definition, EPR is "*an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle*" which becomes responsible for meeting the recovery and recycling obligations of the individual producers[51] (OECD, 2001). Despite EPR being, in theory, an individual obligation, in practice producers often exert this responsibility collectively.
It is possible to distinguish:

- **Individual producer responsibility (IPR)**
- **Collective producer responsibility (CPR)**

In addition to the possibility of developing their own packaging waste management system, producers of packaging waste can transfer their responsibility to another entity that is the Producer Responsibility Organisation (PRO) (E.g. Green Dot company) (ARGUS, 2011).
PROs potentially cover three main functions:

- financing the collection and treatment of the waste by collecting fees from packaging waste producers and public/private entities
- managing the data on waste treatment
- organising training activities (European Commission, 2014)

The financial structure is based on the overall costs for waste management minus the revenues coming from the sales of recovered materials.
In particular, the full costs theoretically include:

- Collection, transport and treatment costs for separately and non-separately collected waste

[50] The producer responsibility regime implements the Directive on Packaging and Packaging Waste (94/62/EC, amended by Directive 2004/12/EC and Directive 852/2018/EC). Also, the Producer Responsibility Obligations (Packaging Waste) Regulations 2007 (as amended) cover recycling and recovery, while the Packaging (Essential Requirements) Regulations 2003 (as amended) cover single market and optimisation aspects.
51 Packaging companies handling 50 tonnes of packaging materials or packaging in the previous calendar year with a turnover of more than £2 million a year (based on the last financial year's accounts) are covered by the scheme.

- Costs for public information and awareness raising
- Costs aimed to promote waste prevention (WP) actions
- Costs for litter prevention and management (Watkins et al., 2017)

The average waste tax for each MS is illustrated in the graph below (Figure 40).

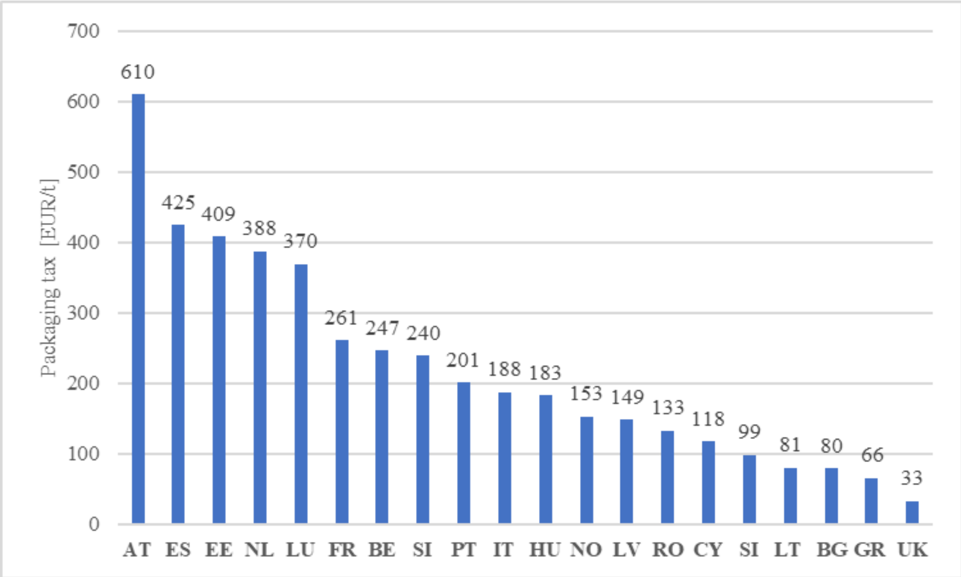


Fig. 40 Packaging tax in European Member State – Source: PROEurope[52], 2017

Around 400 EPR schemes are currently in use globally, most of them in OECD countries (Watckins et al., 2017). In Europe the first EPR schemes were implemented in the 1990s in Germany, France, Austria, Belgium, Luxembourg, Spain, Portugal, Hungary, Finland, Ireland, UK (European Commission, 2014). 26 of the 28 EU MSs have some form of EPR in place for packaging waste to date (Watkins et al., 2017). The current EU landscape on EPR scheme is characterized by a multitude of different factors that completely change the waste management form one MS to another. In fact, EPR may be both mandatory and voluntary, imposing physical/ organisational, financial or informative responsibility on producers; it also may assume financial responsibility and/or partial or full operational responsibility; it may manage household/equivalent packaging vs commercial and/or industrial packaging, or both (Kaffine and O'Reilly, 2015).

The following table shows an overview of the different factors characterizing the EPR scheme currently in use in Europe.

Tab. 11 Compliance schemes for plastic packaging in Europe

[52] PROEurope – Source: https://www.pro-e.org/

	Type of plastic packaging materials				Type of plastic packaging waste			Type of plastic packaging		Type of fee	
	Plastic (in general)	PET/HDPE	EPS	Bioplastics/biodegradable plastics	Household	Commercial/ Industrial	Both	Single use	Multiple use	Basic fee modulation	Eco-modulation fee
Austria				x			x (ARA)	x		x	
Belgium		x			x (Fost-Plus)	X (VAL-I-PAC)		x		x	
Bulgaria		x					x (Ecopack)	x		x	
Cyprus	x						x (Green Dot Cyprus)	x		x	
Czech Republic	x						x (EKO-KOM)	x	x (no fee)	x	
Estonia	x						x (ETO)	x		x	
France	x				x (CITEO)			x			x (CITEO)
Finland	x						x (Finnish Packaging Recycling RINKI Ltd)	x		x	
Germany				x	x (Der Grune Punkt-duale system Deutschland GmbH)			x		x	
Greece	x						x (Hellenic Recovery Recycling Corporation)	x		x	
Hungary	x						x (ÖKO-Pannon)	x		x	
Ireland	x						x (Repak)	x		x	
Italy	x						x (CONAI)	x			x (CONAI)
Latvia				x			x (Latvijas Zalais punkts)	x		x	
Lithuania		x					x (Žaliasis taškas)	x		x	
Luxemborurg	x						x (Valorlux)	x			
Malta	x						x (Greenpak)	x		x	
Netherlands				x			x (Alfafonds Verpakkingen)	x		x	x (ALFAFONDS)
Poland	x						x (Rekopol)	x		x	
Portugal	x						x (Sociedade Ponto Verde)	x		x	
Romania		x					x (ECO - ROM AMBALAJE)	x		x	
Slovakia	x						x (ENVI-PAK)	x		x	
Slovenia		x					x (Slopak)	x		x	
Spain		x			x (ECOEMBES)			x		x	
Sweden	x						x (FTI)	x		x	
UK	x						x	x		x	

All the schemes include some basic fee modulation. The fees for plastic and for composite packaging materials are typically significantly higher than fees for other packaging materials (Pro-Europe, 2017). In addition to basic modulation fee, eco-modulation fees (taking into account environmental aspect such as eco-design for reusability, recyclability etc.) are spreading all over Europe. However, only CITEO in France, Afvalfonds Verpakkingen in the Netherlands and CONAI in Italy have already implemented the eco-modulation fee (Azzurro et al., 2020).

As laid down by the article 182bis of Legislative Decree 152/06, the Italian self-sufficiency of municipal waste management has led the regions to guarantee, as much as possible, the plastic waste treatment internally (Italian government, 2006). This principle has catalysed the launch of a framework of waste operators, consortia and enterprises. Since the legislative frameworks provides measures for post-consumer plastic waste, the system appears more organized than the system for special ones where the competitive market prevails.
Both national and independent consortia exist. As described by the article 221 of the *Consolidated Environmental Law*, National Consortia can be combined with Independent Consortia where packaging producers and recyclers work to independently valorize their own plastic waste (Italian government 2006; Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2019).

The national Packaging Waste Consortia is represented by **CONAI**. Its management was entrusted by law to its member companies: more than 900.000 companies have joined the consortium. The operational management of recovering packaging for each single material (steel, aluminium, paper, wood, plastic, glass) is entrusted to six Material Consortia, one for each material. In the case of plastics, it is carried on by the National Consortium for the Collection and Recycling of Plastic packages named **COREPLA.**

COREPLA system is specifically composed of:

- **Centri Comprensoriali (CC)** – Pre-sorting plants where household PPW are removed from the bag to detect not-PPW
- **Centri di Selezione e Smistamento (CSS)** - Sorting plants where PPW are sorted by polymer and colour
- **Centri di Selezione e Riciclaggio (CSR)** – Sorting an recycling facilities

While some Independent consortia are being validated, PARI, CONIP and CORIPET are already operative (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2014; 2016; 2018).
In particular:

- **PARI** is established by the Italian multiutility HERA S.P.A. operating in the environment, water and energy sectors and approved through the Directorial Decree 5201/2014. It is composed of four companies and works on LDPE flexible packaging
- **CONIP** is approved through the Directorial Decree 28/2016. It is composed of 13 companies (of which 2 manufacturers, 1 recycler and 10 collectors) working on PO secondary and tertiary packaging.
- **CORIPET** is approved through the Directorial Decree 58/2018. Since it works on PET beverage bottles management, it is composed of the main mineral water producers in addition to three recyclers.

Even if special wastes are not considered within this study because of the lack of measures and regulations for this type of waste, COREPLA also plays a subsidiary role for industrial/commercial PPW by providing a framework of platforms such as:

- **PIA - Platforms for general industrial packaging management**
- **PIFU - Platforms for drums and tanks**
- **PEPS - Platform for PS packaging**

The following figure shows the overall consortia working in PPW stream. The area delimited by the grey line is under investigation within this study.

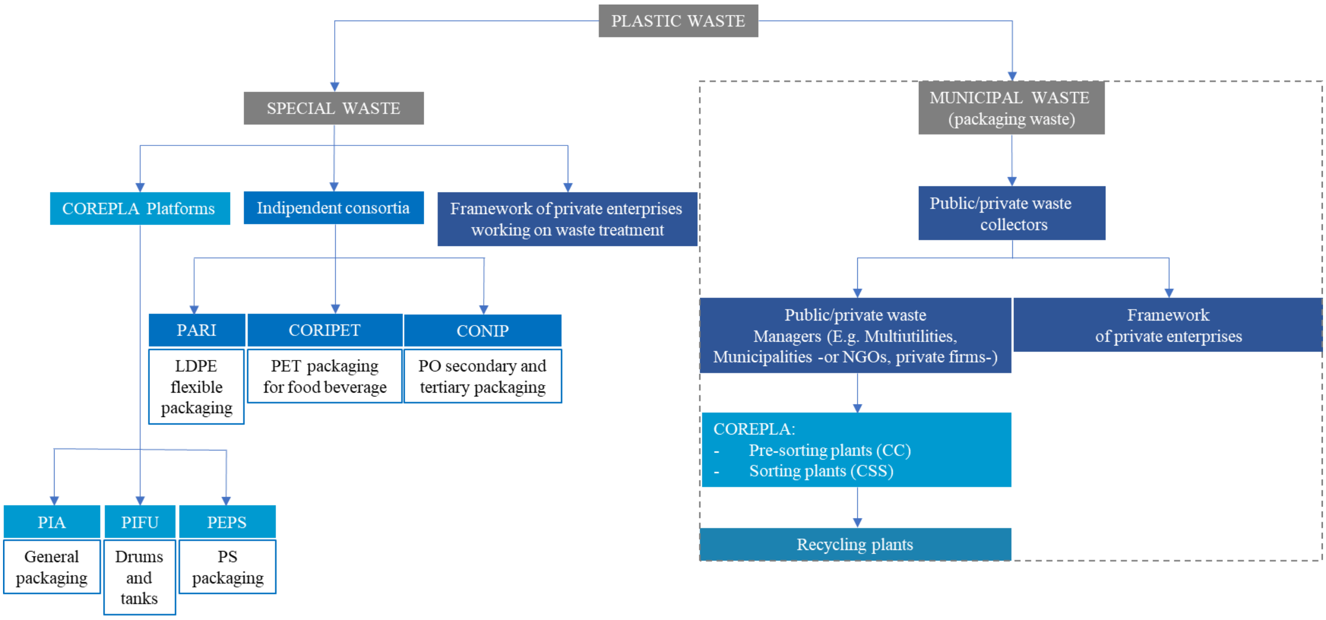


Fig. 41 National plastic waste management system

3.4.1.1 The role of the national plastic packaging consortium in Italy

As mentioned above, the plastic wastes managed by municipalities are generally packaging waste. As result of the application of the EPR principle - where producers and importers are responsible for the waste they generate and Sharing Responsibility - where stakeholders collaborate to pursue the waste hierarchy, COREPLA runs the financial costs about the EoL of municipal PPW.

In particular, municipalities entrust the waste management to COREPLA that is regulated by a specific national framework agreement stipulated (every five years) between the National Municipalities Association (ANCI) and the National Packaging Consortium (CONAI)**.** In 2108, 980 agreements were established in Italy. It involved 7.231 (91%) municipalities, of which 496 established a direct agreement and the remaining 6.375 municipalities relied on certified intermediators.

In addition, COREPLA establishes the so-called Contributo Ambientale CONAI (CAC) with:

- Companies that manufacture or import plastics materials to produce the packaging
- Companies that produce or import plastic packaging
- Companies that produce and use packaging or import packed goods

CAC is a compulsory contribution which serves as a form of financing allowing CONAI (and in this case, COREPLA) to support separate waste collection and packaging waste treatment (CONAI, 2017). That system allows to allocate the responsibilities for the correct environmental management of the packaging and packaging waste produced and used. In 2018, 2.582 firms, were associated to COREPLA (COREPLA, 2019).

A scheme representing the financial and operational organization of the compliance scheme is illustrated in the Figure below (Figure 42).

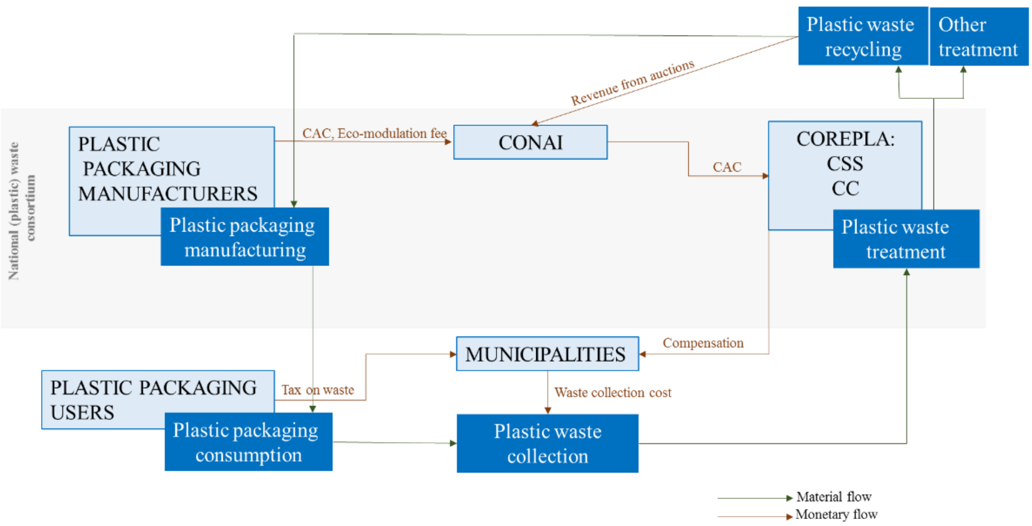


Fig. 42 Financial organization of National plastic waste consortium Corepla[53]

Regarding the fee paid by the plastic packaging producers, COREPLA has implemented an eco-modulation fee where any packaging producers that join the Consortium pays in accordance to the level of recyclability of plastic packaging[54]. Depending on the market of secondary plastics and the quality of collection as well as performance of recycling, CAC is subject to change over the years. The following tables shows the eco-modulations fees approved in the last three years.

Tab. 12 Italian eco-modulation fees for plastic packaging - Source: CONAI, 2018, 2019, 2020

Category	Description	2018	2019	2020
CATEGORY A	Commercial and industrial Packaging	179 EUR/t	150 EUR/t	150 EUR/t
CATEGORY B	Municipal packaging:	208 EUR/t		
CATEGORY B1	Sortable and recyclable municipal packaging[55]	n.a.	208 EUR/t	208 EUR/t
CATEGORY B2	Other sortable and recyclable municipal packaging	n.a.	263 EUR/t	436 EUR/t
CATEGORY C	Not sortable and recyclable packaging	228 EUR/t	369 EUR/t	546 EUR/t

[54] If the packaging is reusable, tax benefits are established. In 2017, 472.401t of food plastic packaging and 2.002.127t of non-food plastic packaging were reused (ISPRA, 2019).

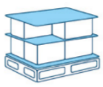
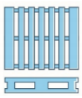
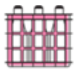
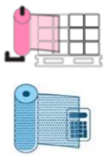
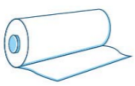
The list of packaging included in each category evolves according to the type of packaging placed on the market and the multitude of factors affecting the WMS. The lists, updated on January 1st, 2020, have been described in the tables below. As reported in the last column of the table 12, the CAC is considerably increased in 2020.

It is due to many factors:

- Chinese waste import ban and therefore, high availability of low-quality plastics in the waste streams
- Increase of the amount of plasmix coming from the municipal PPW stream
- High bid of film and therefore, reduction of the film price
- Increase of incineration costs for the disposal of the plasmix
- Increase of logistics cost due to the storage of plasmix

The category A generally refers to commercial and industrial packaging.

Tab. 13 List of packaging included in the category A – Source: CONAI, 2019

CATEGORY A	
Figure	Description
	Liners, Big bags and bags for industrial applications
	Big bottles (with respective cups) for water distribution
	Covers for pallets
	Crates for industrial and agriculture applications
	Drums
	Interlayers
	Pallet
	Bottles racks
	PE Films (without metal and prints) for industrial and other applications
	Thanks (V>5l)
	Tube and rolls for flexible materials

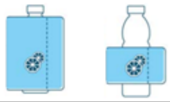
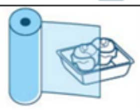
The category B is the most suitable for the recycling of post-consumer plastic packaging waste (PCPPW).

Tab. 14 List of packaging included in the category B1 – Source: CONAI, 2020

CATEGORY B1	
Figure	Description
	Transparent or t/coloured PET bottles and containers without multi-layers (layers made of other polymers or materials, without plastic slevees (or printed slevees)
	Transaprent or t/coloured PET bottles or containers with removable plastic sleeves containing eco-labelling for correct disposal
	Coloured (except for black) HDPE bottles, containers and tanks (Vmax=5l) without plastic sleeves
	Coloured (except for black) HDPE bottles, containers and tanks (Vmax=5l) with removable plastic sleeves containing eco-labelling for correct disposal

Respect to 2019, the category B1 has removed PP bottles, containers and thanks.

Tab. 15 List of packaging included in the category B2 – Source: CONAI, 2020[56]

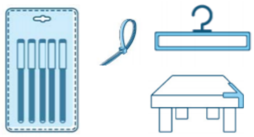
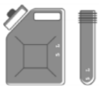
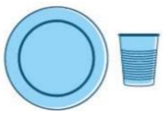
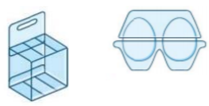
CATEGORY B2	
Figure	**Description**
	Reusable bags (in accordance to the artcle 226bis - D.Lgs. 152/06)
	Biodegradable and compostable carrier bags (in accordance to UNI EN 13432:2002)
	Dispensers
	Caps (different that those of category A)
	No-black slevees made of PE, PPE or PE/PP, without glue, prints and metals and easyly removable (containing information for the consumer about the removal)
	No-black flexible packaging made of PE, PP or PE/PP (without metals, prints) (different that those of category A)
	No-black Rigid packaging made of PP, HDPE (different that those of categores A,B1,C)
	Seed trays and food boxes made of PS and EPS
	HDPE bottles, containers, tanks and other rigid packaging (V_{max}=5l) containing selectable black dye.

Respect to the previous year, HDPE rigid containers containing selectable black dye has been added to the category B2 in 2020.

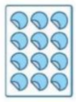
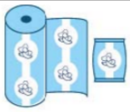
[56] NIR-detectable black colorants have been experimented and placed into the market by Clariant in 2019. Source: https://www.clariant.com/en/Corporate/News/2019/10/Welcome-black-Clariant-launches-NIRdetectable-black-colorants-for-a-wide-range-of-recyclable-polymer.
Other producer is *Colour Tone Masterbatch* – Source: http://www.colourtone-masterbatch.co.uk/pages/lib/innovative.html .

The category C contains all the packaging (both rigid and flexible) that cannot be recycled in an economically efficient way.

Tab. 16 List of rigid packaging included in the category C – Source: CONAI, 2020

	CATEGORY C			
	Figure	Description	Figure	Description
RIGID PACKAGING		Opaque PET bottles and containers		Bottles and contianers with metallic and non-removable components
		Bottles and containers with big sleeve (different that those of category B1)		Capsule
		Multi-layer bottles and containers		EPS non-food boxes
		PET bottles and containers with a pronted sleeve		Other (as swhown in the figures)
		Bottles and containers made of PS, PLA PVC etc (with the exclusion of PET, PE, PP)		Tube and rolls (differents that those of category A)
		Black bottles and drums (V<5l)		Tubes
		Single-use tableware		Other rigid packaging (differents that those of categories A and B1)
		Trays made of EPS		

Tab. 17 List of flexible packaging included in the category C – Source: CONAI, 2020

	CATEGORY C	
	Figure	Description
FLEXIBLE PACKAGING		Sacks and bags (differents that those of categories A ansd B2)
		Laundry basket
		Slevees (differents that those of category B2)
		Flexible packaging (different that those of category B2)
		Adhesive tape
		Net and mash bags
		Multilayer films
		Other flexible packaging (different that those of category B2)

According to the last available data, in 2018 COREPLA has gained 448.902 EUR from the CAC deposited by plastic and plastic packaging manufacturing companies. Part of this contribution has been used to cover the cost of collection, selection, recycling, energy recovery and disposal (E.g. landfill) as well as transportation and logistics. The total cost accounted for 634.911 EUR in 2018. 33 pre-sorting plants and 73 sorting plants managed the total amount of plastic packaging waste managed by COREPLA (COREPLA, 2019). In order to compare 2018 with the year 2017 (that has been used as reference year to analyse the material flow at regional level), the revenue form CAC was 398.700 EUR in 2017 and 448.902 EUR in 2018 (COREPLA, 2019). Additional revenue is given by the economic valorization of the plastics, that accounted for 104.367EUR in 2017 and 141.400 in 2018. The work of the sorting plants is regulated to obtain the following outputs, some of which are sold to national as well as EU remanufacturers (See Table 18).

Tab. 18 Lis of the final products sold by COREPLA through telematic auctions, 2017, 2018
(The new products introduced in 2018 are reported in grey)

Product	Acronym (commercial name)
By-products	**PLASMIX**
By-products	**PLASMIX_FINE**
By-products	**PLASMIX_FINE/F**
By-products	**PLASMIX/F**
Plastic crates	**SELE-CAS/M**
Light blue PET bottles	**SELE-CTA/M**
Coloured PET bottles	**SELE-CTC/M**
Transparent PET bottles	**SELE-CTL/M**
HDPE rigid container (E.g. Detergents containers)	**SELE-CTE/M**
Small/sized (format<A3) films (E.g. Wrappers)	**SELE-FIL/S**
Plastic Films (E.g. Industrial films)	**SELE-FIL/M**
Mixed coloured flexible packaging	**SELE- FILM/C**
Not-coloured flexible packaging (format=A3)	**SELE FILM/N**
Mix of PP packaging (E.g. Jars)	**SELE-IPP/C**
Mix of PO packaging	**SELE-MPO/C**
Mix of rigid PO containers	**SELE-MPR/C**
PET opaque bottles	**SELE-PET/C**
PET trays	**SELE VPET**
PS rigid packaging	**SELE IPS/C**

As already mentioned, part of these products (PET, HDPE and Film products) are sold through telematic auctions into the EU market[57]. Other products are sold according to direct orders stipulated between COREPLA and the single customers.

In 2017, COREPLA managed 1.073.797t of plastic waste (of which 91,2% was PPW) (ANCI, 2019). The overall number of products sent to EU recyclers accounted for 550.000t in the same year. The details per product are listed in the table below. As aforementioned, the revenue from this operation was 104.367 EUR. In the following year, the amount and price of products increased, and the revenue accounted for 141.400 EUR.

[57] Auctions are carried out on-line on platform http://corepla.clearchem.com. Sales auctions of the selected PET and HDPE products are held monthly. Auctions of the selected film are held every three months.

The following table shows the prices and the amounts of products managed in 2017 and 2018.

Tab. 19 List of final products sold by COREPLA through telematic auctions, 2017, 2018 – Source: COREPLA, 2019

Product	Commercial name	Auction (M=every month; Q=every four months; DS=Direct contract)	2017		2018	
			Cost [EUR/t]	Amount [t]	Cost [EUR/t]	Amount [t]
Clear PET bottles	CTL/M	M	303	235.257	430	244.809
Light blue PET bottles	CTA/M	M				
Mixed PET bottles	CTC/M	M				
Opaque PET bottles	PET/C	DS				
PET trays	VPET	DS				
HDPE containers	CTE/M	M	370	68.472	450	69.967
Packaging film	FIL/M	Q	49	71.502	2	84.608
Flexible packaging + Mixed PP packaging	FIL/S + IPP/C	DS + Q	n.a. +122	59.130	1+ 108	72.062
Mixed coloured flexible packaging	FILM/C	DS	n.a.	n.a.	n.a.	n.a.
Mixed packaging	MPR	n.a.	101	120.090	53	140.283
Secondary reducent agent	SRA	DS	n.a.	7.774	n.a.	4.549

The overall Material Flow analysis (MFA) for national plastic packaging and PPW is illustrated below. Since the case study refers to 2017 data, the Sankey diagrams report the MFA for this reference year.

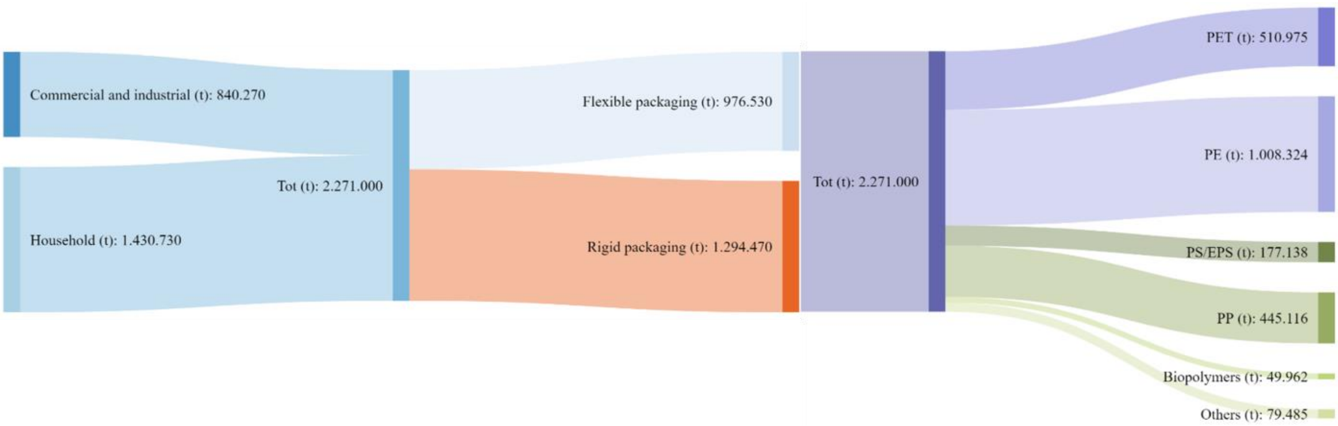


Fig. 43 Plastic packaging market in Italy, 2017. Sankey diagram – Source: COREPLA, 2018

The plastic packaging place on the market accounted for 2.271.000t in 2017 (COREPLA, 2018). In 2018, 2.292.000t were registered (COREPLA, 2019). It follows that the market of plastic packaging is growing more and more. In particular, the demand has registered an evidenced increase for PET, PS/EPS, biopolymers and reduced for PE and PP.

The amount of plastic packaging collected by official scheme accounted for around 50% of the packaging placed on the market (1.074.000kt) in the reference year (COREPLA, 2018). In the following year, 1.220.000t were collected (COREPLA, 2019).

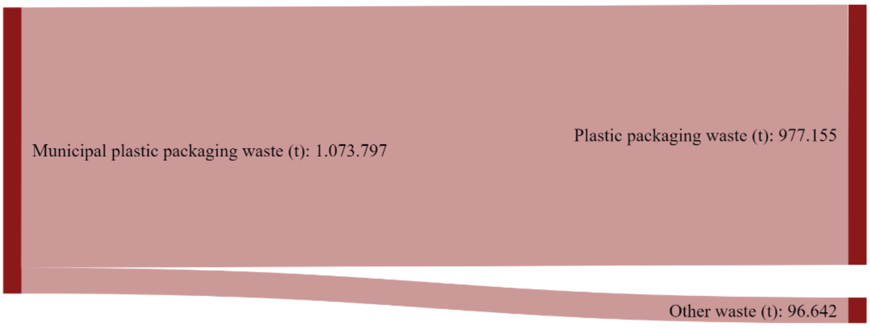


Fig. 44 Municipal plastic waste collection in Italy, 2017. Sankey diagram – Source: COREPLA, 2018

The yearly amount of plastic packaging treated was higher than the amount collected. The following Sankey diagram shows that the main amount of plastic packaging managed in 2017 (including the amount that was stored) has been sent to WtE; it is mainly due to the presence of plasmix (367.753t). Recyclable plastics were (562.224t) sent to recycling through electronic auctions: 95.966t have been recycled abroad (including 7774t of Secondary reducing agent (SRA) that have been sent to the Austrian steel plant named Voestalpine while the remaining amount has been managed by the national recyclers (COREPLA, 2018). In 2018, 92.631t were sold abroad, registering a reduction of 3,5% respect to 2017. It is mainly due to a downtime of Voestalpine. Regarding the product sold in 2018, details are showed in Table 19.

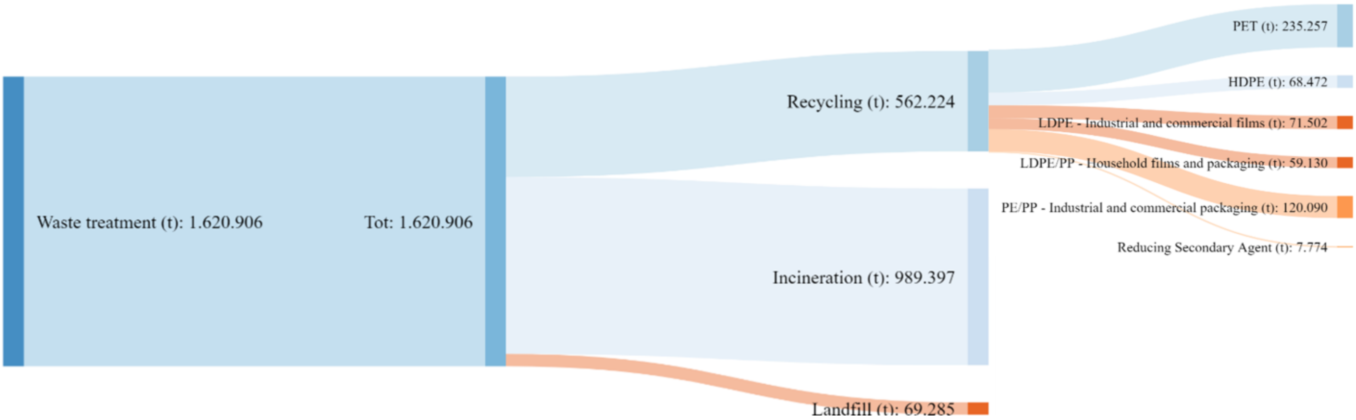


Fig. 45 Plastic packaging waste treatment in Italy, 2017. Sankey diagram. Recycling*=sent to recycling through electronic auctions – Source: COREPLA, 2018

3.5 Other provisions affecting packaging waste

In addition to the packaging tax, other MBIs[58] have been implemented over the years. The use of economic instruments to support the reuse (in some countries) and recycling of packaging waste is one of these measures. Belgium has introduced eco-taxes on certain products put on the market. Finland encourages the reuse of disposable drink containers. Taxes on primary packaging and secondary packaging with a volume of less than 20 litres and on bags of plastics or paper with a volume of more than 5 litres exist in Denmark.

[58] MBIs are policy instruments that use markets, price, and other economic variables to incorporate the external cost of production or consumption activities through taxes or charges on processes or products, or by creating property rights and facilitating the establishment of a proxy market for the use of environmental services.

Austria and the Netherland has provided taxation system for packaging landfilling and incineration without energy recovery. Italy has banned landfilling of collected packaging waste (European Commission, 2012).
In general, the framework of environmental taxes has highlighted the reduction of the amount of plastic packaging disposed in incineration plants or landfill sites.

A report from the EC named *Use of economic instruments and waste management performances* suggests that there is a relationship between higher landfill taxes and lower percentages of municipal waste being sent to landfill, identifying three MSs macro groups:

- MSs with high total charges for landfill and low percentages of municipal waste landfilled
- MSs with mid-to-high-range of total charges and mid-range percentages landfilled
- MSs with low total charges and high percentages landfilled (See Table 20)

Tab. 20 Effect of landfilling taxes in municipal waste generation. Analysis per Member State – Source: Bio Intelligence Service and European Commission, 2011

Group number	Member States
1	Austria, Belgium, Germany, Denmark, Luxembourg, Netherlands, Sweden
2	Finland, France, Ireland, Italy, Slovenia, United Kingdom
3	Bulgaria, Czech Republic, Greece, Hungary, Lithuania, Latvia, Poland, Portugal, Romania, Slovakia, Cyprus, Estonia, Spain

About incineration, just Austria, Belgium, Denmark, France, Germany, Netherlands, Portugal and Spain are currently implementing an incineration tax system. Sweden and United Kingdom are planning to activate this kind of MBI by 2020 (European Commission, 2016). These countries are in line with the strategy on waste management finance established by the EC. In fact, the recent report *Taxonomy* has excluded WTE incineration from the list of economic activities considered sustainable (European Technical Group on Sustainable Finance, 2019). Therefore, EC is strongly promoting other waste valorisation such as recycling, reuse as well as prevention.

In addition to environmental taxes, MBIs includes:

- **Pay As You Throw (PAYT)**
- **DRS**

PAYT system is an additional MBI that breaks with tradition of common waste taxes, based on a fixed fee or property size. PAYT is based on the amount of waste throw away. In the vast majority of cases, the overall cost of the service is funded through a combination of flat rate fees or taxes and a variable element which may be linked to one or more of the following elements:

- the choice of container size (volume-based schemes)
- the weight of material collected in a given container (weight-based schemes)
- the frequency with which a container is set out for collection (frequency-based schemes)
- the number of sacks set out for collection (sack-based schemes).

PAYT system is implemented in Austria, Belgium Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Luxembourg, Netherlands, Sweden, Slovakia, Slovenia, Estonia and United Kingdom.

DRS is intended to act as an economic incentive to recycle tailored for post-consumer phase. This system incentivises the return of used packaging through the use of a refundable deposit. Consumers pay a small fee charge when they purchase the beverage containers, which is partially or fully refunded when the empty container is to designated collection points, typically located in retail outlets or other centralised locations, where they are collected and recycled. As for now, only Croatia, Denmark, Estonia, Finland, Germany, Lithuania, Netherlands, Norway, Sweden have implemented DRS for packaging (especially for plastic bottles) (RELOOP, 2017)

The following scheme shows the rate for DRS in the countries implementing this MBI.

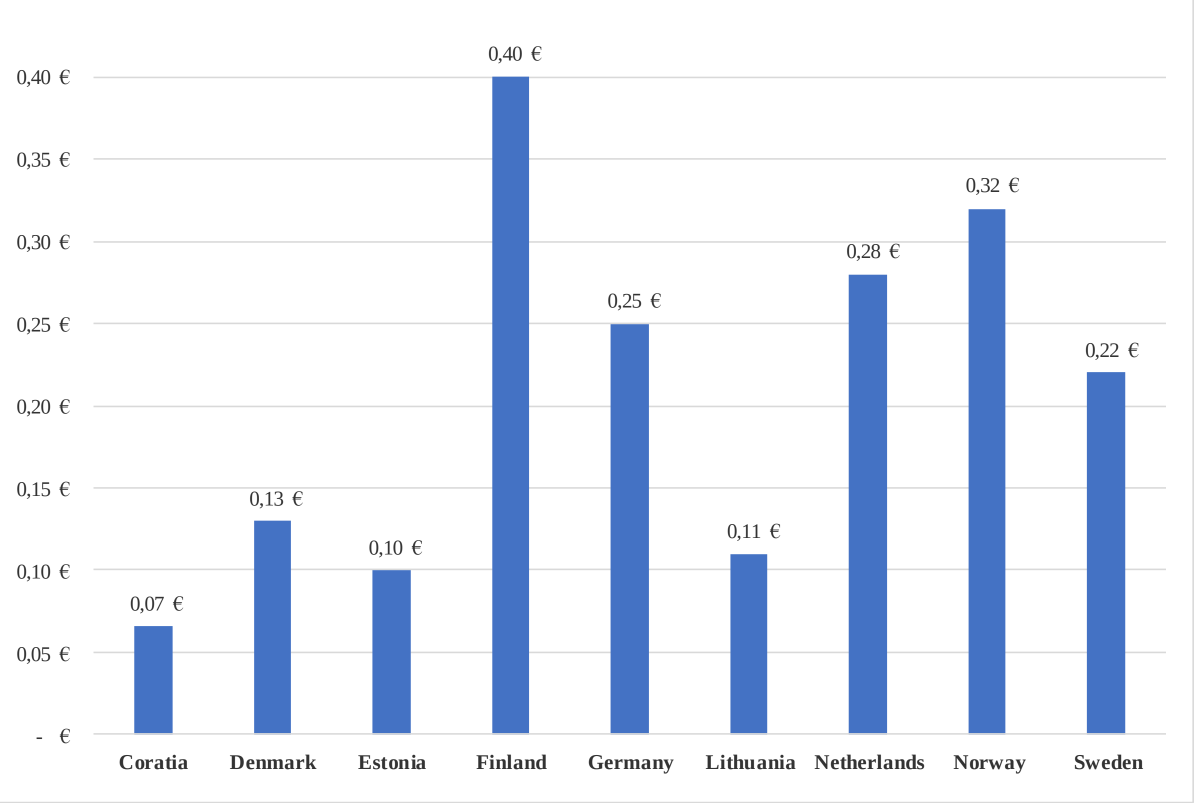


Fig. 46 Deposit Refund System. Analysis by Member State - Source: Reloop, 2017

The Directive on carrier plastic bags[59] has introduces a taxation for this good. Of the 34 countries with some form of plastic bag legislation, 27 countries (representing about 80%) have implemented some type of tax on the manufacture, distribution and EoL phase of plastic bags. Some countries have specific national legislation on plastic bags while others have packaging laws or regulations, which govern plastic bags (UNEP, 2018).

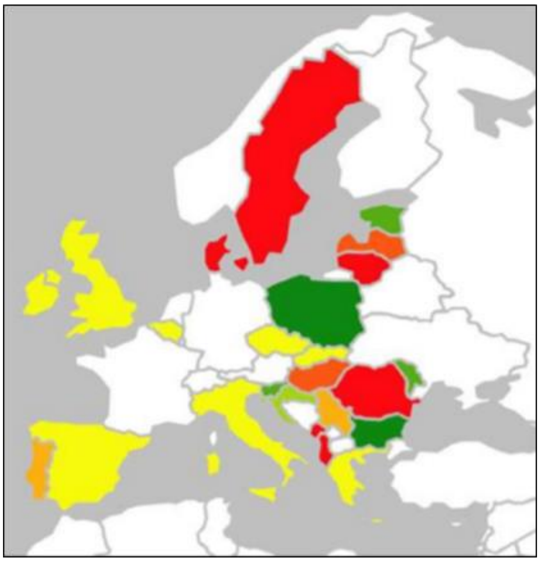
There are seven predominant approaches (or combinations of) implemented among the considered area:

- Tax on manufacture of plastic bags
- Tax on distribution of plastic bags
- Tax on manufacture and distribution of plastic bags
- Fee on distribution of plastic bags to end-users
- Fee on the distribution of plastic bags to end-users and tax on distribution
- Fee on the distribution of plastic bags to end-user and tax on manufacture
- Fee on the distribution of plastic bags to end-users, tax on manufacture and distribution

[59] Plastic carrier bags are carrier bags, with or without handle, made of plastic, which are supplied to consumers at the point of sale of goods or products (UNEP, 2018).

The following figure and table (Figure 47 and Table 21) show the analyses of Plastic bags taxation per approach.

Tab. 21 Type of taxation for plastic bags – Source: UNEP, 2018



Tax on manufacture of plastic bags;
Tax on distribution of plastic bags;
Tax on manufacture and distribution of plastic bags;
Fee on distribution of plastic bags to end-users;
Fee on the distribution of plastic bags to end-users and tax on distribution;
Fee on the distribution of plastic bags to end-user and tax on manufacture;
Fee on the distribution of plastic bags to end-users, tax on manufacture and distribution.

Fig. 47 Plastic bags taxation. Analysis by Member State and type of taxation – Source: UNEP, 2018

The Commission is strongly pledging on effort to reduce virgin plastic use and to improve the competitive position of recycled plastic. It proposed in 2018 a national contribution calculated on the amount of non-recycled plastic packaging waste in each Member State, in the context of the Multiannual Financial Framework (MFF) that is already ongoing. Another example is given by reducing VAT for products containing recycled materials or shifting the tax burden from labour to polluting activities (European Commission, 2019d).

In Italy, many economic measures have been established in the last year to facilitate the transition towards a sustainable packaging. The Decree-Law n.34/2019 has introduced an economic incentive for the purchase of packaging made of roughly 75% of recycled materials (including plastics). The incentive consists of a 25% **discount in the tax credit** for the 2020 financial status of commercial and economic national activities. It may be higher if the packaging is also reusable and recyclable (Italian government, 2019). To push the market of SPs, additional measures have been provided by the Minister of the Environment within the National Action Plan of Green Public Procurement (GPP PAN). As defined by the EC, GPP is "*the approach by which Public Bodies integrate environmental criteria and/or requirements into all stages of their procurement process, thus encouraging the development of environmental technologies and the spread of environmentally sound products, by seeking and choosing outcomes and solutions that have the least* *possible impact on the environment throughout their whole life-cycle*". In order to activate the GPP, environmental minimum criteria have been established through specific decrees issued by the Ministry of the Environment and the Protection of Natural Resources (2006). The minimum environmental criteria consist of specific technical considerations of environmental (and, where possible, ethical/social) requirements (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2006). With the new Code of Contract (Legislative Decree 50/2016), and with subsequent amendments (Legislative Decree 56/2017), GPP is no longer a voluntary instrument but has become compulsory. For plastics packaging, the existing **minimum environmental criteria** sets 60% of recycled plastics for primary, secondary, tertiary plastic packaging used in furniture, electric-electronic equipment's (EEEs), waste containers and 30% in primary reusable packaging used for medical sanitation items[60]. The current government has also proposed a **plastic tax** named **MACSI**. The tax has been included in the law 160/2019 and will come into force in July with the first payment expected for October. The tax regards one-way plastic packaging, with the exception of bio based and compostable plastics (as certified by the technical law UNI EN 13432:2002) has well as recycled plastics[61]. The commitment towards the use of bio-based and compostable plastics is also fostered by the establishment of a discount on **the Value Added Tax (VAT),** accounting for 10% with a with a ceiling of 20.000 EUR in 2020 (Italian government, 2020a). Another proposal comes from the working group Quality Recycling composed of composed of the National Agency for Environment (ENEA), COREPLA, CONAI, Rubber-Plastic Federation and the environmental not-profit organization (NGO) Legambiente. The Working group has proposed a VAT if converters manufacture products using at least 30% of recycled plastics. Finally, many financial measures have been established to prevent waste. The Italina Decree Law *Misure Urgenti Per Il Contrasto Dei Cambiamenti Climatici E La Promozione Dell'economia Verde* is going to introduce a VAT to shops and supermarkets selling bulk products. The discount, accountig for 20%, will be applicable in the period 2020-2022 (Italian government, 2020b).

3.6 Impact of plastic packaging in the environment

In this paragraph the effects of packaging in the environment have been discussed. Many life-cycle assessment (LCA) studies have been carried out on packages and packaging materials since the 1970s. Most of those aimed to compare beverage packaging systems (Pongracz, 2007) or alternative materials substitution. Some LCA studies commissioned by the plastic industry have found that plastic can help to reduce some environmental impacts (European Commission, 2018). Especially in case of packaging, plastics are preferable to other materials for its contribution to the reduction of food waste and emission furing the transportation stage. However, owing to many factors such as the functional unit, the system boundaries (geographical, natural as well as life cycle), the data quality, and the allocation, results can significantly change and no general conclusion can be figure out. The following discussion has been done from a qualitative point of view encompassing each step of the value chain.

As described above, plastic packaging here analysed are fossil-fuel based. Plastic packaging contains resins as well as a huge number of additives. As already mentioned, additives are manufactured by the chemical companies as technologically advanced products than basic chemicals. The impact of petro-chemical company in terms of GHG is well-know (OECD, 2001). However, as evidenced by the US EPA, the chemical industry is also the biggest emitter of carcinogens released (US EPA, 1997). In fact, chemicals such as plasticisers and stabilisers found in plastics could leak out during the usage (OECD, 2001). This problem is particularly arguably in food packaging application where the migration mechanism could directly affect the human health (Cherif Lahimer, 2017). The amount of potentially toxic substances (PoTSs) migrating into food depends upon its initial concentration in the packaging product, the nature of food, the food-additive

[60] Ministero dell'ambiente – Source: https://www.minambiente.it/pagina/i-criteri-ambientali-minimi
[61] Packaging intended to contain medical devices are exempted.

interactions and time–temperature-storage conditions (Hahladakis et al., 2018). This means that certainty about the real impact of this substances on the environment and the human health are not well defined. After the consumption, additional impacts are generated during the EoL stage. Referring to legal waste treatment options, even if the amount of PPW sent to recycling is higher than the amount incinerated, the process losses make the WtE process the main waste disposal option. The challenge affecting the recycling system has risen the disposal of plastic waste into WtE plants that, being unevenly spread across the EU, have caused additional emissions owing to the transportation of waste for long distances (Wilts et al., 2016). Despite significant worldwide advances in management, treatment and recycling in the last three decades, the largest fraction of plastic waste still possibly ends upon dumpsites or is openly burned, emitting carbon monoxide (CO) and carbon dioxide (CO_2). The illegal combustions of plastics containing certain types of additives such as Brominated flame retardants (BFRs) cause hazardous substances emission (E.g. acid gases and unintentional persistent organic pollutants (POPs) such as dioxins (UNEP, 2015). Uncontrolled recycling is also challenging owing to the transfer of potentially harmful substances or PoTSs from waste to secondary plastics (Chen et al., 2010). Landfilling is still a common way to deal with PPW (PlasticsRecyclersEurope, 2015). Finally, a large amount of PPW ends up in the environment and in the oceans as marine litter each year (Jambeck et al., 2015). As reported by Ocean Conservancy (2019), packaging (glass and plastic bottles, cans, paper cups, paper and plastic wrappings) are the main constituents of litter because of its short lifespan and improperly management at EoL (Jambeck et al., 2015). In particular, the results figured out by six of beach clean-ups around the world show that out of almost 14 million items collected, five of the ten most commonly found items (by the number of items found) are plastic packaging (Ocean Conservancy, 2019). Entering into details, the ‘single-use’ plastic packaging accounts for 50% of the marine litter (European Commission, 2018; Joint Research Centre, 2017). This problem is particularly argued in Southern Asia and China, where 4 to 12 Mt od plastic packaging is swept down rivers and ends in the oceans thus contributing to make the problem global (d’Ambrières, 2019).

4 SUSTAINABLE PACKAGING IN A CIRCULAR ECONOMY

Even if there are various definitions (Kirchherr et al., 2017), the most prominent one has been provided by Ellen Mac Arthur Foundation (2017) defining CE as "*an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with re-storing, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impede reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models*". In CE, materials and products circulate as long as possible, thus leading to natural resources preservation and waste minimization.

According to Bocken et al. (2016), the following two fundamental strategies towards the cycling of resources can be identified:

- Slowing resource loops through the design of long-life goods and product-life extension
- Closing resource loops through the recycling

These two approaches are distinct from a third approach towards reducing resource flows that is identified in design and process optimization

While the first strategy is oriented to product condition, the second one is strictly enclosed on waste state and the third could be achieved in any case. This approach reflects the waste hierarchy (European Parliament and of the Council, 2008) where prevention is prioritized to recycling. Prevention activities are generally aimed to reduce the amount of resources and wastes, while recycling makes effort on waste valorisation. In particular, prevention measures pursuit the maximization of resource use efficiency, while recycling strives to add and maintain the material value as long and better as possible.

CE practices, affecting prevention at first and recycling than, play an essential role in fostering the rethinking of the plastic packaging value chain. The following table shows the main actions fostering the transition towards a circular plastic packaging value chain in accordance the priorities established by the waste hierarchy.

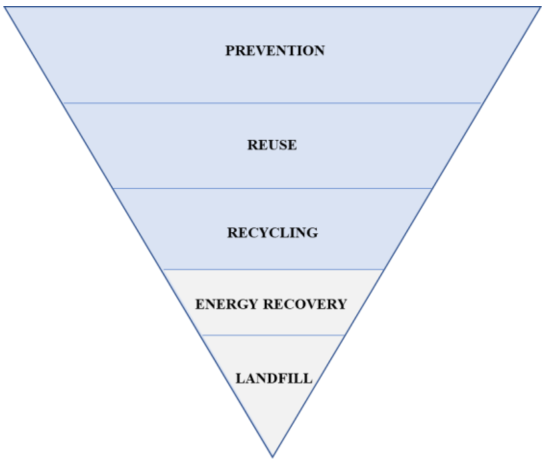


Fig. 48 Waste hierarchy – Source: European Commission, 2008

According to the waste hierarchy, CE in plastic packaging field prioritizes five fields of action, as follows:

a. **No packaging (Servitization)**
b. **Packaging minimization**

c. **Packaging waste minimization**
d. **Packaging reusability**
e. **Packaging recyclability**

While zero-packaging and packaging minimization fulfils the prevention concept, packaging recyclability is part of the recycling principle. Reusing (or preparing for reuse) can be seen as forms of prevention.
As highlighted by Tencati et al. (2016) and Finnveden et al. (2013), the main goal of preventing waste has not been successfully achieved yet and solutions are mainly focused on the end-of-pipe. The same conclusions are expressed by Wilts et al. (2012) and Zorpas et al. (2017) demonstrating how waste management measures prevail on prevention.

4.1 Prevention in plastic packaging field

According to the definition, prevention takes place before products are identified as waste, distinguishing it from other waste related activities (Vancini, 2000). As defined by the article 3, comma 12 of Waste Framework Directive (WFD), prevention means "*measures taken before a substance, material or product has become waste, that reduce:*

(a) the quantity of waste, including through the re-use of products or the extension of the life-span of products;
(b) the adverse impacts of the generated waste on the environment and human health;
or (c) the content of harmful substances in materials and products" (European Parliament and the council of the European Union, 2008).

Prevention, and in particular WP is also coupled to strict prevention (or dematerialization) referring to demand reduction before product life cycle (Price and Joseph, 2000). As illustrated in the figure below, prevention applications are strong if they are aimed at reducing the use in quantitative terms, and they are weak if applied to decline in the intensity of use (De Bruyn and Opschoor, 1997).

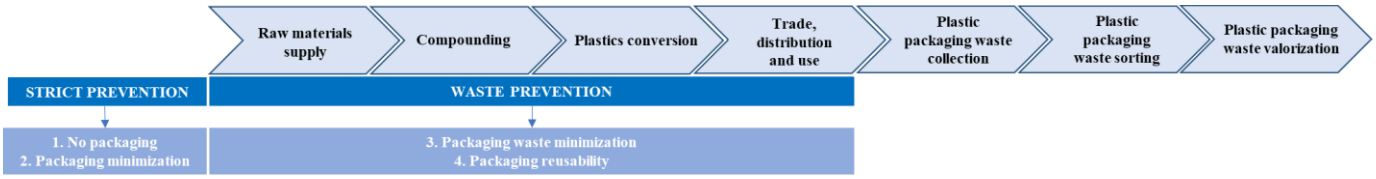


Fig. 49 Prevention along the plastic packaging value chain

According to the principles characterizing the strict prevention/dematerialization and the WP, the following figures shows the main actions that promote CE in packaging field.

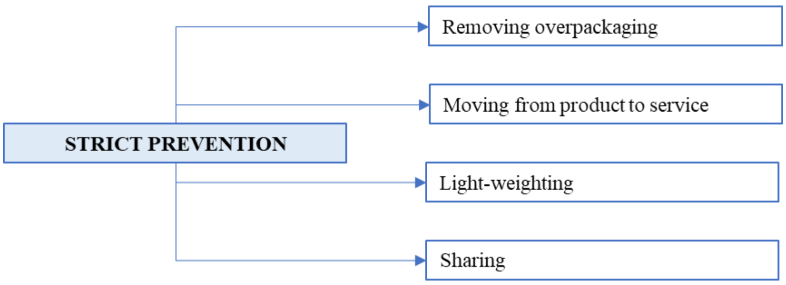


Fig. 50 Actions promoting strict prevention in plastic packaging field

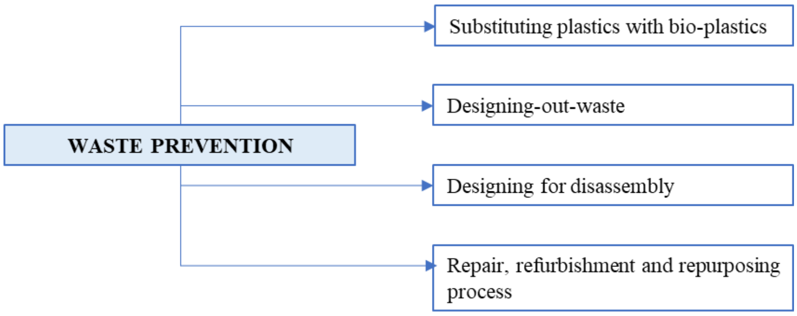


Fig. 51 Actions promoting waste prevention in plastic packaging field

According to the same definition, prevention can be investigated by three perspectives: quantitative, qualitative and a third perspective oriented to avoid hazardous substances. Contextualizing it into plastic fields, quantitative prevention results in a reduction of the amount of the plastic waste, while qualitative prevention is aimed at reducing the impact in the environment and human health. The prevention of hazards refers to a reduction of the contamination of a waste stream with Bisfenol A (BPA), phthalates and hazardous additives (Laner et al., 2009).

WASTE PREVENTION	
QUALITATIVE	• Sustainable supply chain • Clean energy • Process and logistic optimization • Awareness • Clean up activities • Proper disposal • Waste valorization
QUANTITATIVE	• Fossil-based materials substitution (with bio-plastics or recycled plastics) • Out-waste design • Design for disassembly • Design for reuse • Reuse, repair, refurbishment and repurposing process
PREVENTION OF HAZARDS	• Fossil-based mateial substitution • Additives' reduction • Chemical substances'reduction

Fig. 52 List of actions promoting qualitative, quantitative prevention and prevention of hazards in plastic packaging field

Quantitative plastic prevention fosters the reduction of plastic waste. At design and production stage, reducing at source covers a more important role than waste minimization. In particular, dematerialisation, followed by light-weighting are the key principles to achieve that goal. While weight reduction is aimed to

reduce raw materials at the source, servitization furthers the total elimination of resource by promoting solutions that supplement traditional product offerings. Many case studies are tested in packaging fields, both in Business to business (BtoB) and Business to Consumer (BtoC). Return system are spreading in BtoB, especially in e-commerce sector. In BtoC, Nessi et al. (2013) studied the substitution of bottled water consumed domestically by public potable water from the tap, and the substitution of single-use packaged liquid detergents by those distributed loose through self-dispensing systems and refillable containers. Another aspect reducing the environmental impact caused by the plastic packaging value chain is the substitution of fossil-based plastics with bio-plastics whose source should be waste biomass generating from food and similar industries; however, this type of plastic is currently neither sorted for recycling, nor composted with organic waste, and it often ends up with other plastics diverted for sorting and recycling, contaminating the high-value plastics streams (Hahladakis and Iacovidu, 2018).
The light-weighting design aims to reduce the raw material consumption. In this case, a trend has been seen in recent years is the shift from rigid packaging formats to flexible formats that are lighter, with superior barrier properties and easy to decorate and brand (Smithers Pira, 2017).
The so-called eco-design, including designing-out-waste, supports the realization of these issues by an anticipatory approach based on which the life-span, the functions, and the generation of refuses and waste are considered as a problem to be dealt with at the end of the production process or after the product has completed its useful life, but must be kept in mind from the beginning (Lieder and Rashid, 2016; Ghisellini et al., 2016). When generated, waste could be reduced by applying recycling within a production process (Laner and Rechberger, 2009). This practice is common among plastic converters. It is defined primary recycling and involves the re-introduction of clean scrap of single polymer into the extrusion cycle (Al-Salem et al., 2009). All the issues related to the extension of the products lifespan can be considered in this field: reuse, repair and refurbishment and repurposing can be taken into account (Gentil et al., 2011). At the same time, maximizing the value within the lifespan through the sharing business models is becoming spread.

Qualitative plastic WP encourages the reduction of environmental and health impacts of generated plastic waste coming from post-industrial and post-consumer waste streams. It takes on even more significance if actions contribute to the reduction of MPP and its impact on the marine life and the food chain. This ambition is also pursued by adopting a systemic thinking approach and a life-cycle perspective (Eriksen et al, 2013): at production phase, mismanagement and accidents could disperse flakes and granulates (Lechner et al., 2014); at consumption step, microplastics in cosmetics and synthetic fibres in textile as well as the increasing abrasion of tyres are some representative examples (Wagner et al., 2018). At EoL, improper disposal, lack of end-of-pipe and clean-up activities, inefficient wastewater treatment surely cause environmental impacts. At the contrary, appropriate plastic waste collection, sorting and recycling supported by Best available technologies (BATs) adoption, cleaner energy use and cleaning system application give a great contribution to the nature safeguard. Consumer choice behaviours also influence the environmental concerns. Increasing awareness on sustainable issues determines a huge impact on changing life habits.

Hazardousness prevention includes all the measures dealing with the reduction of harmful substances in materials and products, and therefore, in plastic resins and goods. Resin is composed by plastic polymers and additives such as plasticisers, flame retardants, heat stabilisers, antioxidants, light stabilisers, lubricants, acid scavengers, antimicrobial agents, anti-static agents, pigments, blowing agents and fillers (Rosato, 2011). Several of these additives, especially BFRs, phthalate plasticizers, lead heat stabilizers are hazardous to human health and the environment (Murphy, 2001). Designing by avoiding these substances is necessary to protect environment as well as human health. Investments on research and development (R&D) allows to better understand hazard and risk assessment of potential migration and uncontrolled release as well as human exposure and related effects on health (Lithner, 2011) during the consumption phase.

For industry, it is clear that win-win solutions are possible where there are cost savings but also environmental benefits. In some cases, this has been achieved by switching the packaging material to something that can be more easily recovered and recycled.

4.2 Reuse in plastic packaging field

Directive 94/62/EC defines reuse as "*any operation by which packaging, which has been designed to accomplish a minimum number of trips or rotations, within its lifecycle is refilled or used for the same purpose for which it was designed, with or without the support of auxiliary products present on the market enabling the packaging to be refilled; such reused packaging will become packaging waste when no longer subject to reuse*." The norm EN 13429 specifies the requirements that packaging has to fulfil to be classified as reusable.

As shown in the Figure below, reuse system are implemented in BtoB as well as in BtoC market.

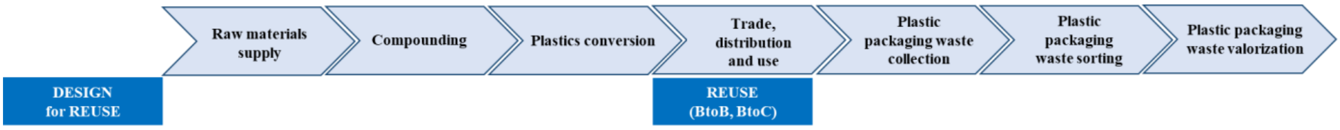


Fig. 53 Design for reuse (and effective reuse) along the plastic packaging value chain

Refillable bottles are the best-known examples of reusable packages. Another application of reuse is the so-called refill pack and is spready common in the e-commerce sector. Reusable transport packaging is common in industrial supply chains too (Saphire, 1994). Models are shown in the figure below.

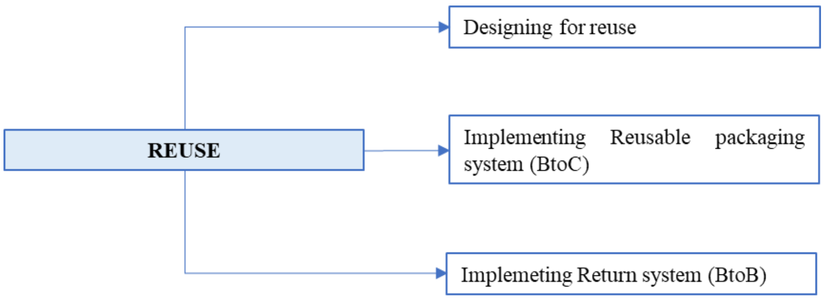


Fig. 54 Actions promoting reuse in plastic packaging field

No targets have been established until now for the assessment of reusable packaging.

4.3 Recycling in plastic packaging field

Recycling stage can add to circular and sustainable plastic value chain the transformation of a plastic waste into finished and semi-finished plastic products aiming to maintain material value as long as possible (Di Maio and Rem, 2015).

The WFD defines recycling as *"any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used ad fuels or for backfilling operations"*.

The recycling process is evaluated by the End-of-waste status that is verified when:

a. *the substance or object is commonly used for specific purposes;*
b. *a market or demand exists for such a substance or object;*
c. *the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;*
d. *the use of the substance or object will not lead to overall adverse environmental or human health impact* (European Parliament and the council of the European Union, 2008).

Recycling is pursued by an effort at design stage implementing the design for recycling (DforR) approach. In fact, huge environmental problems for plastic packaging derive from the way in which a product is manufactured.

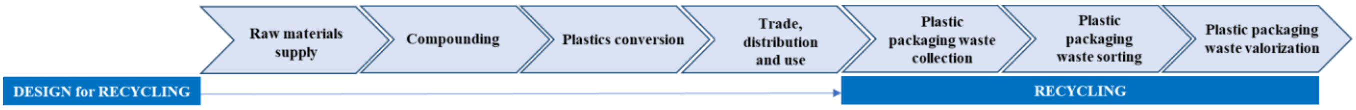


Fig. 55 Design for recycling (and effective recycling) along the plastic packaging value chain

The Innventia AB model[62] below illustrated the optimum pack design that is achieved by maximizing environmental and economic benefit and minimizing packaging material as shown in figure below.

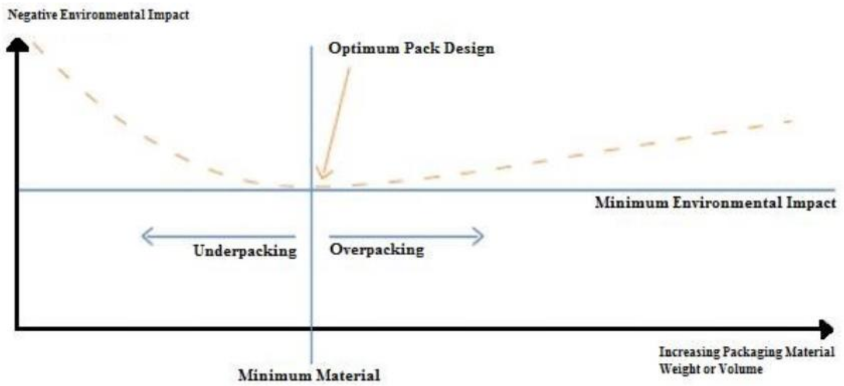


Fig. 56 Soras Curve – Source: Innventia AB

The requirements for maximize the recycling performance of plastic packaging are deeply described in the paragraph 8.2.
General models characterizing the recycling are shown in the figure below.

[62] The Soras Curve was developed by Innventia AB, a major Sweden-based R&D company in the fields of pulp, paper, graphics media, packaging and bio-refining.

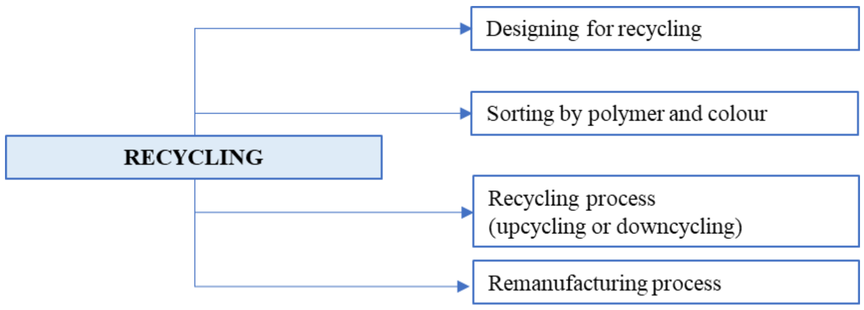


Fig. 57 Actions promoting waste recycling in plastic packaging field

Scholars are working on measuring the value generated by the application of CE models. According to the waste hierarchy, more value is generated during the production and consumption phase. The building block of waste valorization, and in particular recycling, is generating added value to waste through the extension of the intrinsic value of the material itself.

5 ENVISIONING A FUTURE SCENARIO FOR PLASTICS CIRCULARITY: FROM EUROPEAN TO REGIONAL GOALS AND OBJECTIVES

5.1 Normative transforming scenario: recyclability and recycling by 2030

As described in the chapter 1, the future scenario corresponds with the scenario envisioned by the European Commission within the ***Action plan on Circular economy*** that includes the ***European Strategy for Plastics in a circular economy*** since plastic materials have been considered as one of the five priority sectors which the Commission has highlighted measures. These issues contribute to a wider project on sustainability established through the Sustainable Development Goals (SDGs) collected within the ***Agenda 2030*** (UNEP, 2015). In particular, the *Closing the loop* Action plan on circular economy, published in December 2015, pledged specifically to promote a systemic approach across the entire value chain by enabling multi-stakeholder engagement[63] (European Commission, 2015, Bourguignon 2016). As part of the plan, the revision of the WFD published in June 2018 encompasses the ***Packaging and Packaging Waste Directive (PPWD)*** where essential requirements on eco-design (including recyclability) have been introduced (European Parliament and the Council of the European Union, 2018). The PPWD has previously amended an additional time though the ***Directive 2015/720 EC*** aimed to reduce the use of plastic bags by forcing the consumption reduction of lightweight bags and the elimination of very lightweight plastic carrier bags (European Parliament and the Council of the European Union, 2015). As aforementioned, EC highlighted the importance of the plastic related problems publishing the Strategy on plastics in 2018 (European Commission., 2018). Because of the urgency and importance of the plastic_related problems, this legislative initiative is the first EU-wide policy framework adopting a material-specific lifecycle approach where gradually reduction on waste shipment, inter-connected value chain and development of sustainable and innovative materials are the pivotal goals. The same concepts have been taken over in the **European Green Deal** where measures to address the problem of microplastics as well as actions to promote reusability and recyclability have been included in the related roadmap (European Commission, 2019b). According to these intentions, a policy on Sustainable Products is expected for March 2020. This element is particularly important because of strictly related to the mission of ensuring that all packaging placed in the EU market will be reusable or recyclable in an economically viable manner by 2030 (European Commission, 2019d).

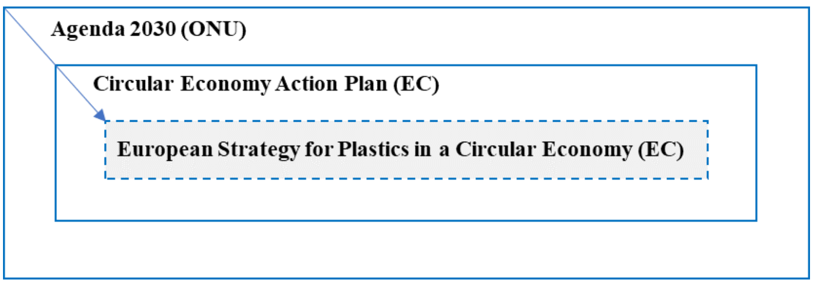


Fig. 58 Normative transforming scenario

[63] A Circular economy stakeholder platform has been launched by the European Commission within the Circular Economy Action plan.

Indeed, the EC is working on:

- Proposal directive on microplastic in cosmetics as part of the ***Marine Strategy Framework Directive***
- A clear regulatory framework for plastics with biodegradable properties (E.g. **Report on oxo-degradable plastics**[64])
- Legislative measures aimed to cut the consumption of the main plastic products found on sea (E.g. Directive on Single-Use-Plastics (SUPs))
- Legislative measure to prevent packaging and reduce over-packaging (E.g. ***Drinking Water Directive***)
- Policy instrument to improve waste collection and sorting (E.g. EPR)
- Policy instrument to foster sustainable product design
- Legislative measures on port reception facilities to recover plastic waste from sea (E.g. ***Directive on port reception facilities for the delivery of waste from ships***)
- **Policy Framework on Sustainable Products** (European Commission, 2019d)
- Incentives to support global, national and regional actions on the understanding and avoiding the rise of marine litter
- Awareness-raising activities on sustainable consumption (E.g. **Ecolabel and GPP**)
- Requirement for eco-design (E.g. **Eco-design Directive**)
- Information to address the interface between chemical, products and waste management (E.g. ***Communication 2018/032***)
- Information campaigns aimed to increase consumers awareness on environmental issues

Among them, the ***Directive on the reduction of the impact of certain plastic products on the environment,*** known as Directive on SUPs, was published in June 2019. The Directive establishes measures focused on the elimination, reduction and limitation of certain plastic products on the market, since they are responsible for the marine pollution. Additional measures affect the design and the collection of specific plastic goods.

Many legislative measures have been implemented in previous years especially for food contact materials (FCM). In addition to general requirements incorporated in ***Framework Regulation (EC) No 1935/2004, Regulation (EC) No 2023/2006*** as mended by the ***Regulation (EC) 282*****/2008** and ***Regulation (EC) No 10/2011*** setting rules for designing, manufacturing as well as informing about the composition of FCM (according to the list of authorized and not authorized substances (European Commission 2011), additional policy promoting circularity was published in 2008. Thanks to the strong cooperation between the EU Commission and the European Food Safety Authority (EFSA), the *Regulation (EC) No 282/2008* laid down rules for the authorization of processes manufacturing food packaging made of recycled plastic (Commission Regulation, 2008).

Finally, additional Directives and Regulations contribute to feed the overall legislative framework characterizing plastics and their applications (see Table 22).

[64] Oxo-degradable plastics are plastic materials that include additives which, through oxidation, lead to the fragmentation of the plastic material into micro fragments or to chemical decomposition (European Commission, 2018)

Tab. 22 Legislative framework on plastics

Legislation/formal document on plastic waste prevention	Production	Consumption	Waste management	Lifecycle
Best Available Techniques Reference Document (BREFs) *in the Production of Polymers*				
Directive 2015/720 EC consumption of lightweight plastic carrier bags				
Eco-Management and Audit Scheme Regulation – ISO 14001				
Regulation (EC) No 66/2010 on the EU Ecolabel – ISO 14024				
Directive 2010/75/EU - Industrial Emission Directive (IED)				
Directive 2001/95/EC on general product safety				
Regulation 1907/2006 EC on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH Regulation)				
Regulation (EC) No 2023/2006 on good manufacturing practice for materials and articles intended to come into contact with food				
Regulation (EC) No 1272/2008 (CLP Regulation)				
Regulation 750/2010 on maximum residue levels for certain pesticides in or on certain products				
COM 2018/32 on the implementation of the circular economy package: options to address the interface between chemical, product and waste legislation				
Regulation (EC) No 850/2004 on Persistent Organic Pollutants Directive (POPs Directive)				
Waste Framework Directive (WFD) and related revisions				
Directive on the reduction of the impact of certain plastic products on the environment (SUPs Directive)				

The following figure (Figure 59) shows the key and supporting policies laid down the normative transforming scenario in the EU dimension.

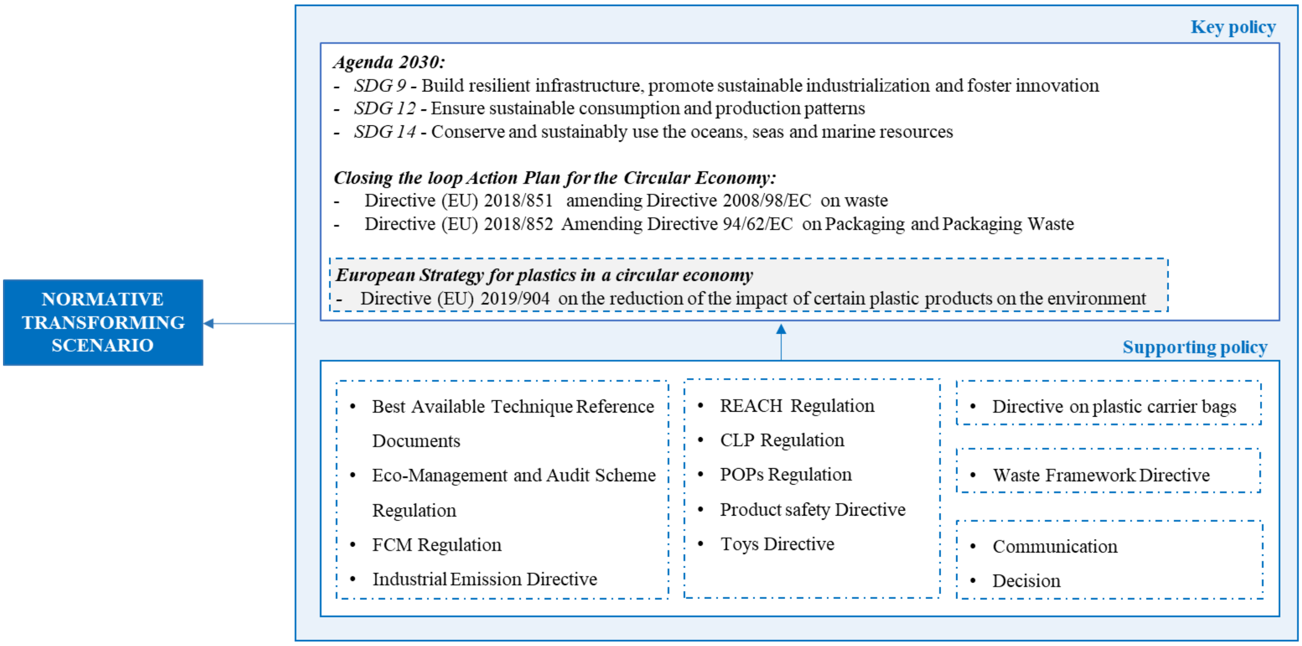


Fig. 59 Normative transforming scenario (European dimension)

According to the Article 2, MSs shall bring into force the laws, regulations and administrative provisions necessary to comply with the PPWD by 5 July 2020. The Italian government has included some insights in the so-called ***Law of European Delegation***. It will amend the existing ***Legislative Decree 152/06*** as already amended by the ***Legislative Decree 205/2010***. Specifically to plastics, the ***Law 123/2017 on plastic carrier bags***, the ***Law 296/2006*** by which the Ministers of the Economy, Finance and Economic Development has adopted the ***Public Consumption Sustainability Action Plan*** **(**also called PAN GPP), the Proposal Law ***Salva Mare*** for the plastic waste found in marine environment, the national program ***#IoSonoAmbiente*** (and the relative **#Plastic free initiatives**), the recent ***Legislative Decree Clima*** **(**that allocate funds to implement sustainable measures by which incentives for free packaging shops) and the very recent ***Budget Law 160/2019*** (which establishes the much-maligned plastic tax) represent the national commitment towards the plastics issues (See Figure 60).

Since the study is focused at the regional dimension, an overview on the regional legislative framework on circular economy and plastics established in ERR has been provided.

While Italian government has already been working on the national law for circular economy[65], Emilia Romagna has accelerated this step, first with the approval of ***Law n.16/2015 on circular economy***, then with the ***Regional Waste Management Plan*** **(RWMP)** and finally, with the **Regional Strategy on plastics** named ***PlasticFreER*** .

The legislative framework establishes a multitude of actions aimed to prevent the consumption of raw materials, reduce the waste generation and valorize waste and scraps (Regione Emilia Romagna, 2015; 2016).

[65] The national government has published a document entitled *Verso un modello di economia circolare per l'Italia*. It also gets ready to transpose the *Circular Economy Package* through the *Delegation Law*.

This mission is supported by the implementation of the following main actions:

- Establishment of a permanent coordination on by-products[66]
- Establishment of a permanent forum on CE
- Plan of supporting finance system for waste management
- Implementation of PAYT tariffs
- Promotion and launch of reuse centres

within the CE law (Regione Emilia Romagna, 2015) and the following measures:

- Establishment of a common room working on defining the roadmap
- Substitution of one-way plastic containers and bottles in regional offices, hospital caterings, schools and firms as well as public events (including sporting events)
- Collection of plastic waste in marine and urban environments through the organization of the "Clean up the word" event
- Making available of economic and financial instruments

within the Regional Plastic Strategy (Regione Emilia Romagna, 2019).

As mentioned above, that activities are implemented coherently with the RWMP where, efforts on waste reduction, waste collection improvement and waste valorization optimization are included (Regione Emilia Romagna, 2016).

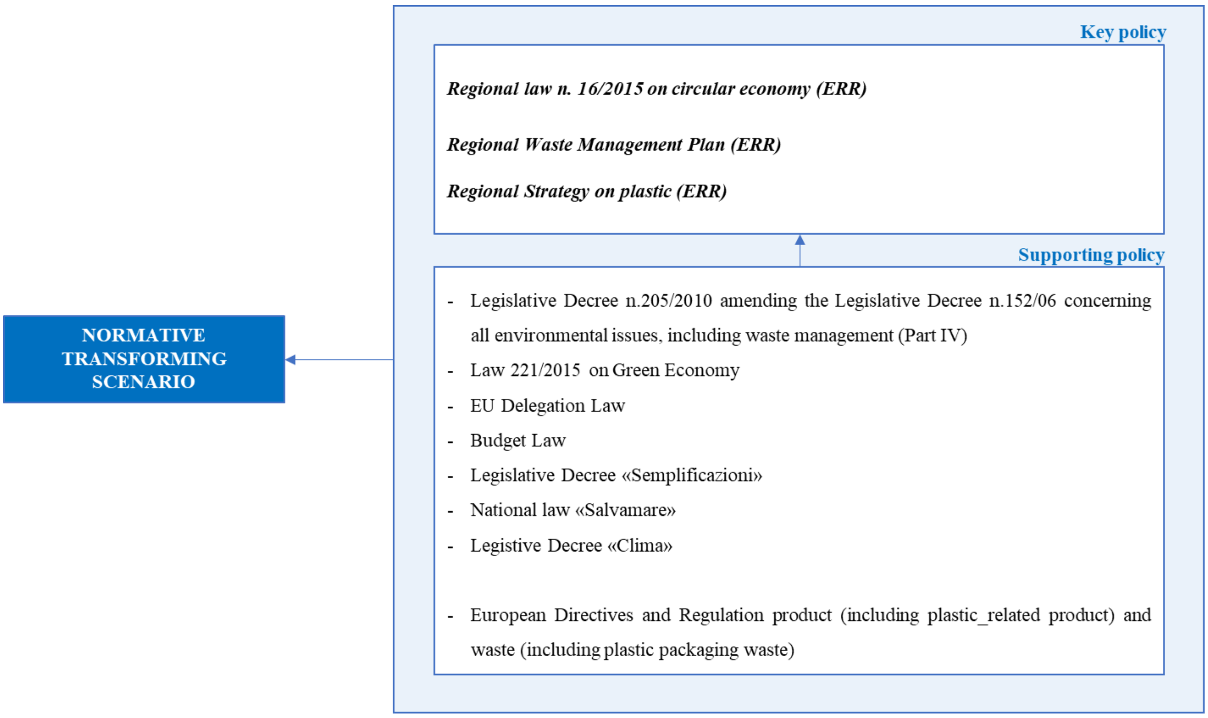


Fig. 60 Normative transforming scenario (Regional dimension)

5.2 Goal definition: recyclability, recycling and circularity

The LT future concerning the plastic system (including the impacts caused by the littering[67]) envisioned in the Agenda 2030 are expressed by the **SDG 9** aimed to build resilient infrastructure, promote inclusive and

[66] In 2020, the by-products worktable published the Statement on the valorization of plastic scraps.
[67] SDG 14 is not strictly related to plastics recyclability and recycling however, proper waste management remains essential for the prevention of all litter, including marine litter.

sustainable industrialization and foster innovation, the **SDG 12** about ensuring sustainable consumption and production patterns and the **SDG 14** regarding the conservation and sustainable use of oceans, seas and marine resources for sustainable development are more related to plastic (UNEP, 2015).
Closely connected to plastics, the main challenges, strategies and opportunities for a more sustainable and safer consumption and production patterns of plastics are figured out by the *European Strategy for Plastics in a Circular Economy* (European Commission, 2018).

The following quantitative targets have been outlined by the Strategy:

- **By 2030, all plastics packaging placed on the EU market will be either reusable or can be recyclable in a cost-effective manner**
- **By 2030, more than half of plastics waste generated in Europe will be recycled**
- **By 2030, sorting and recycling capacity will increase fourfold since 2015,** leading to the creation of 200 000 new jobs, spread across Europe
- **By 2030, secondary plastic market will increase fourfold since 2015**

To support the fulfilment of that ambitious targets, additional supporting targets have been provided by:

- the *SUPs Directive* where:

- Eco-design requirements have been established for beverage bottles identified in the part F of the Annex[68.] In particular, **from 2025, PET beverage bottles should contain at least 25 % recycled plastic[69] and from 2030, PET beverage bottles should contain at least 30 % recycled plastic**[70].
- EPR has been established for fast using food containers, packets and wrappers made from flexible material containing food (that are intended for immediate consumption), beverage containers (including composite beverage packaging) with a capacity of up to three litres (including caps and lids) and lightweight plastic carrier bags (as described in the part E of the Annex).
- Collection rate has been set for **beverage bottle** identified in the part F of the Annex. In particular, **77% and 90% of that products should be respectively collected by 2025 and 2029**[71].
- Market restriction have been forced for cotton bud sticks, stick for balloons, cutlery, plates, stirrers, straws and oxo-degradable plastic food container
- **25% consumption reduction target have been established for food containers and cups for beverage by 2025**

- the *PPWD* where:

- New ambitious recycling rate have been established for packaging (including plastic packaging). In particular, from 31 December 2025, a minimum of 65 % by weight of all packaging waste should be recycled. In addition, from 31 December 2030, the recycling rate will be 70%. **For plastic packaging, the recycling rate is fixed at 50% by 2025 and 55% by 2030**.

- the *Circular Economy Package* where:

- A **binding landfill target to reduce landfill to maximum of 10% of municipal waste should be achieved by 2035**

[68] Beverage bottles with a capacity of up to three litres, including their caps and lids, but not: (a) glass or metal beverage bottles that have caps and lids made from plastic, (b) beverage bottles intended and used for food for special medical purposes as defined in point (g) of Article 2 of Regulation (EU) No 609/2013 that is in liquid form
[69] calculated as an average for all PET bottles placed on the market on the territory of that MS.
[70] calculated as an average for all PET bottles placed on the market on the territory of that MS.
[71] The collection rate is calculated respect to the amount of beverage bottles placed on the market in a given year by weight in each MS.

- Separate collection for hazardous household waste (by end 2022), bio-waste (by end 2023), textiles (by end 2025) have to enter into force.
- 65% recycling rate of municipal waste should be achieved by 2035

Although the *Directive on plastic carrier bags* was published earlier, supporting targets aimed to make the recycling simpler, were provided. The Directive includes the consumption reduction of lightweight bags (ensuring that the annual consumption level does not exceed 90 lightweight plastic carrier bags per person by 31 December 2019 and 40 lightweight plastic carrier bags per person by 31 December 2025 or equivalent targets set in weight) and the elimination of very lightweight plastic carrier bags (categorized as illegal, today).

These targets are here summarised (See Table 23).

Tab. 23 Framework of legislative objectives (European dimension)

Policy		Objective	Target	Year
Agenda 2030	SDG9	9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure,		
		9.2 Promote inclusive and sustainable industrialization		2030
		9.3 Increase the access of small-scale industrial and other enterprises		
		9.4 Upgrade infrastructure and retrofit industries to make them sustainable		2030
		9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors		2030
		9.C Significantly increase access to information and communications technology		2020
	SDG12	12.2 sustainable management and efficient use of natural resources		2030
		12.4 Achieve the environmentally sound management of chemicals and all wastes throughout their life cycle		2020
		12.5 substantially reduce waste generation through prevention, reduction, recycling and reuse		2030
		12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices		
		12.C Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions		
	SDG 14	14.1 Prevent and significantly reduce marine pollution of all kinds		2025
Circular economy package	Waste Directive	Municipal waste recycling	2030	65%
		Landfilling reduction	2035	10%
		Separate collection of hazardous household waste	2022	
	Packaging and packaging waste directive	Packaging waste recycling	2025	65%
		Packaging waste recycling	2030	70%
		Plastic packaging waste recycling	2025	50%
		Plastic packaging waste recycling	2030	55%
Plastics Strategy		Plastics packaging placed on the European market will be either reusable or can be recycled in a cost-effective manner	2030	100%
		Quadruplication of sorting and recycling capacity since 2015	2030	
		Quadruplication of secondary plastic market since 2015	2030	
	SUPs Directive	Introduction of recycled plastics in PET beverage bottles	2025	25%
		Introduction of recycled plastics in PET beverage bottles	2030	30%
		Separate collection for beverage bottles	2025	77%
		Separate collection for beverage bottles	2029	90%

		EPR fast using Food containers, Packets and wrappers made from flexible material containing food that is intended for immediate consumption, Beverage containers (including composite beverage packaging) with a capacity of up to three litres (including caps and lids) and Lightweight plastic carrier bags		
		Market restriction for cotton bud sticks, stick for balloons, cutlery, plates, stirrers, straws and oxo-degradable plastic food container		
		Consumption reduction target for food containers and cups for beverage	2025	25%

Contextualizing the analysis to ERR, the targets established by the *Regional law on circular economy* and the RWMP are included in the Table below (Table 24) (Regione Emilia Romagna 2015; 2016).

Tab. 24 Framework of legislative objectives (Regional dimension) –

Policy		Objective	Target	Year
Law on circular economy		Reduction of municipal waste generation (per capita)	20-25%	2020
		Separate collection of municipal waste	73%	2020
		Material recovery (recycling)	70%	2020
		Self-sufficiency for waste management	100%	2020
		Landfilling rate		2020
RWMP	Plastic waste	Plastic waste generation	253.222t	2020
		Separate collection of plastic waste	124,161t	2020
		Recycling rate of plastic waste	22%	2020
		Recycling of plastic waste	54,631t	2020

The following chart (Figure 61) illustrates the targets on recyclability and effective recycling of plastic packaging by 2020, 2015 and 2030. While recyclability is part of the Plastics Strategy, the plastic packaging recycling targets are established within the PPWD.

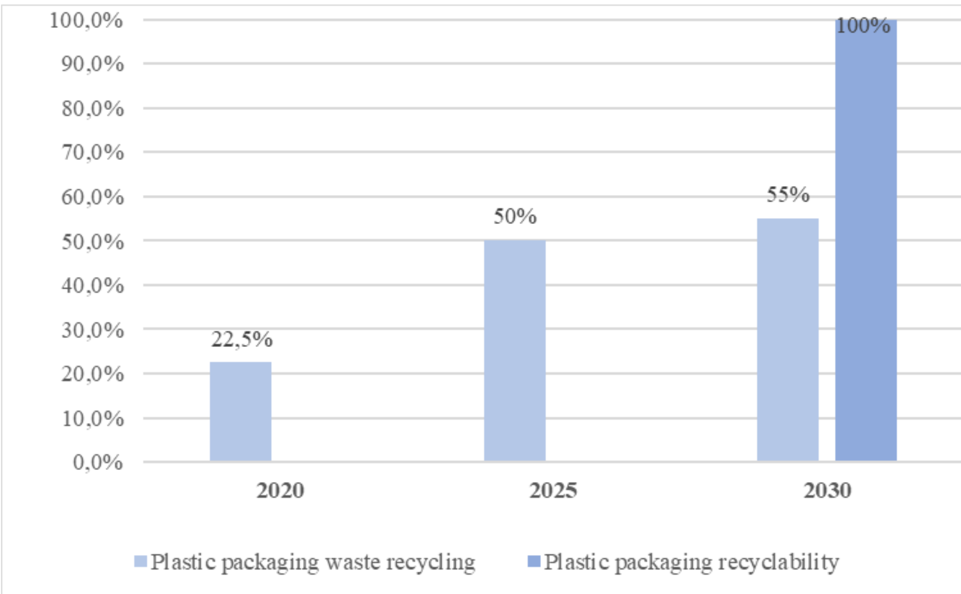


Fig. 61 European and regional targets on plastic packaging recyclability and recycling[72]

The current regional plastic packaging recycling rate refers to the previous amendment of PPWD. It entered into force to achieve the 2008 recycling rate, but it is still in force. In this context, it represents a ST target. However, each EU MS (and consequently EU regions) must transpose the revised PPWD by 5 July 2020. Therefore, ERR will incorporate two additional targets to the existing one. These additional targets are categorized as MT and LT targets.

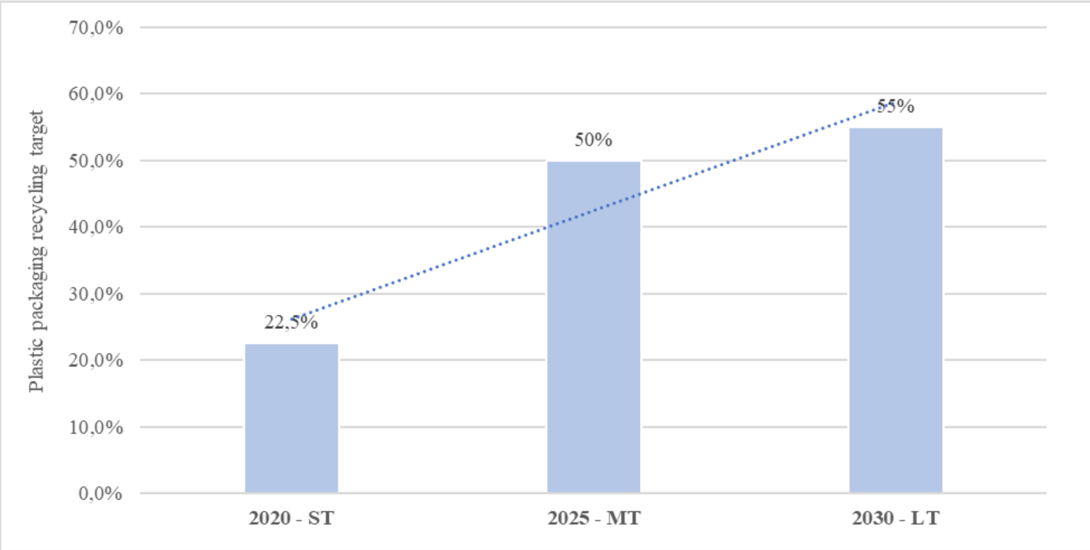


Fig. 62 Short, medium and long term targets on plastic packaging recycling

Summarizing, the work thesis embossed a future vision affecting recyclability and effective recycling (and circularity) of plastic waste.

The final goals that laid down the future scenario are:

- **100% recyclability of plastic packaging by 2030**
- **55% recycling rate for plastic packaging by 2030**

-

The achievement of these goals is supported by additional auxiliary goals that affect the preliminary steps of the recycling chain:

- Plastic waste reduction where regional 2020 target is established
- Separate plastic waste collection (including quantity and quality) where both EU and regional targets have been established.

In order to contextualize this vision in ERR, it is necessary to understand the current situation at first and, identify the gap between the present and the future then. Consequently, the quantitative-qualitative analysis will support the gap analysis elaboration.

[72] The 2020 target refers to 2008 one as it was established within the EU Directive 94/62/CE. This directive has been modified and integrated by the EU Directive 2004/12/CE that has been transposed in Italy through the Legislative Decree 152/06. The Decree has increased the EU plastic recycling target from 22,5% to 26%. This target is still in force. The regional target is 20%.

5.3 Backcasting process: foreword (2018) and backward (2030) analysis

As mentioned in the chapter 1, the backcasting process links the current situation to the envisioned sustainable future. As shown in the figure below (Figure 63), the current plastic packaging recycling target is 22,5% and it is identified as ST target. The MT and LT targets are about twice the ST target. The achievement of these ambitious targets should be respectively done in 8 and 13 years (where the starting year is 2017, the reference year of this work).

In 2017, the regional recycling rate was 22%, accounting for 62.319t. The recycling rate is calculated as the amount of municipal plastic packaging waste (MPPW) (including household and similar waste managed by the municipalities) treated through the R3 treatment code (corresponding to the material valorization of organic substances) over the total amount of plastics collected in the separate and mixed waste collection.
Many factors affect the rate, such as:

- the high generation of plastic waste (that accounted for 279.818t in 2017)
- the generation of municipal/urban plastic packaging waste as waste collected by separate collection scheme (that accounted for 132.773t in 2017)
- the considerable presence of plastic waste in the mixed waste stream (that accounted for 147.045t in 2017)[73]
- the presence of contaminants and non-recyclable plastics and plastic components and in general, the quality of dry recyclable materials (Velis and Brunner, 2013)
- the performance of selection process
- the cost of waste treatment and generally, the market of SPs

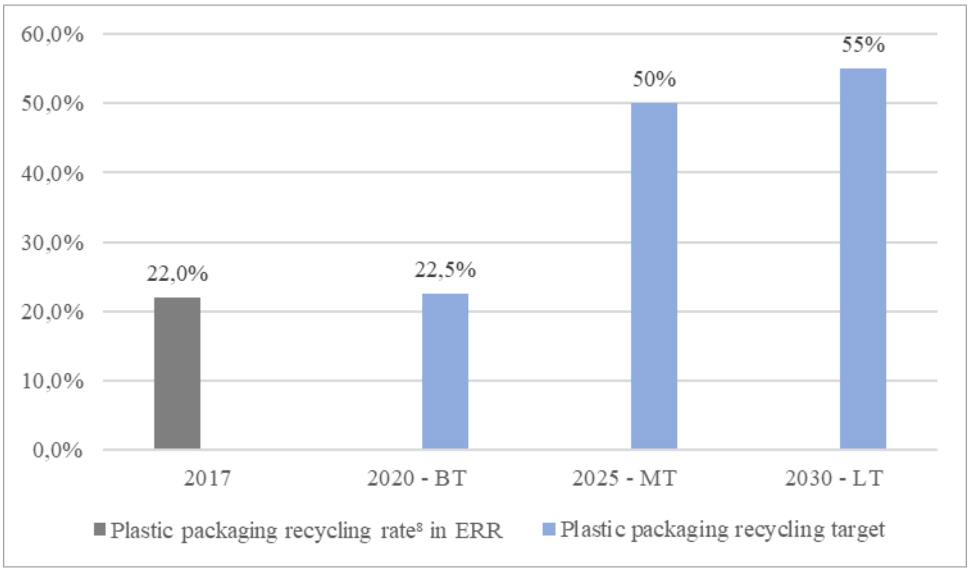


Fig. 63 Comparison between the current regional plastic packaging recycling rate and the ST, MT and LT plastic packaging recycling targets

In a BaU, the target reaches the regional target (20%) and is really closed to the EU ST target (22,5%). However, additional 91.581t are necessary to reach the LT objective. It is not possible according to the

[73] Dara are source from “Chi l’ha visti” report published by ARPAE – Source: file:///C:/Users/utente/Downloads/pubblicazione_rifiuti_WEB.pdf

existing situation. This means that a systemic rethinking of the actual plastic packaging value chain is necessary. Working on the factors affecting the recycling performance, a multitude of measures should be implemented. Measures aimed to reduce the waste, increase the collection and recycling performance as well as simplify the design should be enforced in the next years.

Since backcasting enhances the possibility of identifying radical innovations and changes in the future compared to the present situation (Quist and Vergragt, 2006), it is particularly suitable for this case.

Once the starting and the end points have been established, backcasting is a technique that comes back from a future scenario (1A,1B) to the current situation (2A,2B), identifying and assessing changes and actions for that future to come true (See Figure 64).

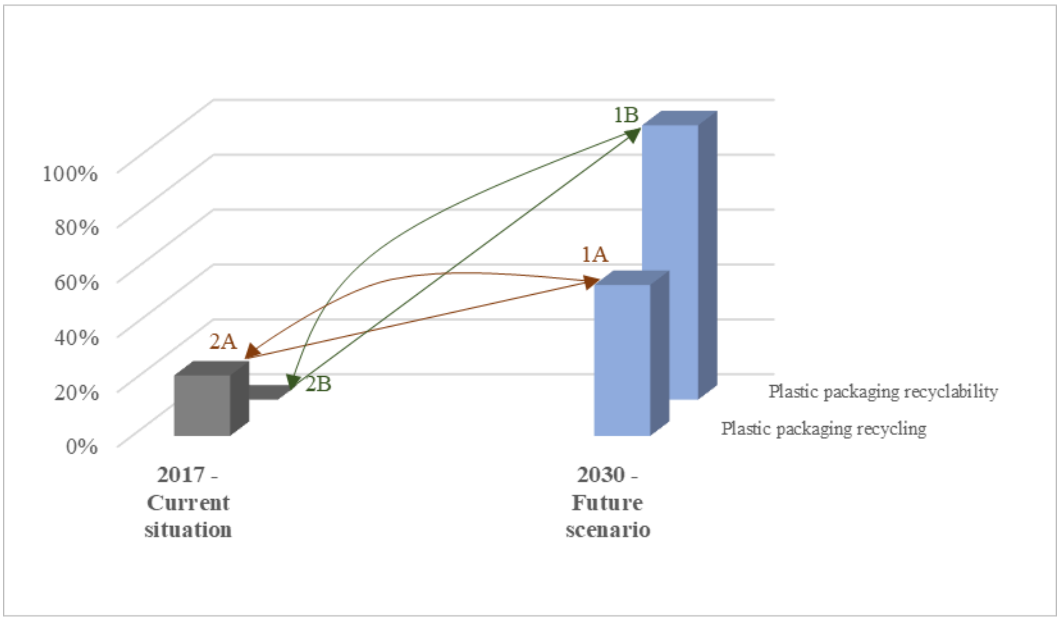


Fig. 64 Comparison between current situation and future scenario on plastic packaging recycling and recyclability

This forward-backward process helps to identify the objectives to reach the goals. The present work aims to find a solution that takes into account the recyclability and the recycling of plastic packaging.
The working plan should be enforced to include the following actions:

- **Establish requirements for plastic packaging recyclability**
- **Monitor and optimize the regional recycling throughput**
- **Introduce metrics assessing the real recycling yield and the circularity of plastics**

Consequently:

- **Support SMEs in switching their product design towards recyclability**
- **Get data on the recycling process**
- **Reinforce the recycling infrastructure**
- **Improve the market of SPs**
- **Encourage the (upcycling) recycling**

Each action should finally be evidence and fact based. It follows that, at the following strategy (reported in the Chapter 8) should follow a robust action plan.

5.4 Guiding principle definition: decoupling economic growth from environmental impact

The entire process is guided by specific principles aimed to go strictly to the final goals. As recommended by Holmberg (1998), defining a framework set of guiding principles support the simplification of complex problems, and then the alignment of the planning with the principles.

The guiding principles characterizing the process implementation are such that any type of action creates profit without impact the environment. Decoupling indicators cover the process of separating economic growth from related adverse environmental impacts (Zorpas et al., 2017). As Van Ewijk and Stegemann, pointed out in 2016 (2016), decoupling implies breaking the link between waste generation use ad economic output. Bontempi (2017) considers the strict decoupling affecting the reduction of primary resource extraction per unit of economy activity that means using less materials and obtain a profitable economic output anyway. These concepts are numerically translated into the Kuznet Curve (KC) and its versions (E.g. Economic Kuznet Curve (EKC), Waste Kuznet Curve (WKC)) (Fischer-Kowalski and Amann, 2001; Seppälä et al., 2001). As shown in the figure below (Figure 65), KC reports an initial correlated increase between income per capita or GDP and pollutant/emissions until a transition point after which the continued rises in per capita income result in a decrease in environmental degradation (Tsiamis et al., 2018).

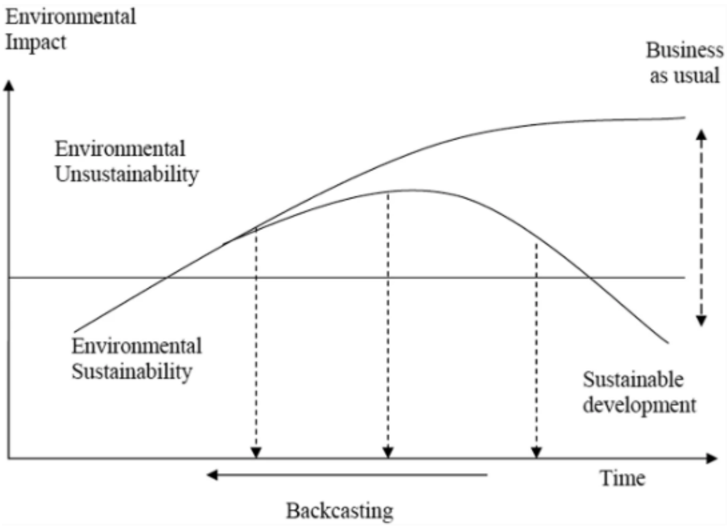


Fig. 65 Stylized Kuznet curve – Source: Parlow, 2014

In Europe, it has been observed that decoupling potentially exists due to policy implementation, regulations, and tax penalties (Tsiamis et al., 2018). However, no uniform standards have been adopted yet to measure decoupling trends. Typically, economic performance (GDP) is compared with resource use indicator. In the case of the *EU Roadmap to a Resource-Efficient Europe*, the main indicator used is GDP divided by Direct Material Consumption (DMC). Circular Economy Action Plan and the European Strategy for plastics in a circular economy adopt the decoupling as principle with no yet existing measure on its performance.

This principle has a great potential to guide the process because of the strict correlation between GDP per capita and packaging consumption per capita. As demonstrated by Worrel and Rauter (2014), GDP is strongly connected to packaging material consumption in Europe (R_2=0,97) and to population density (R_2=0,99).

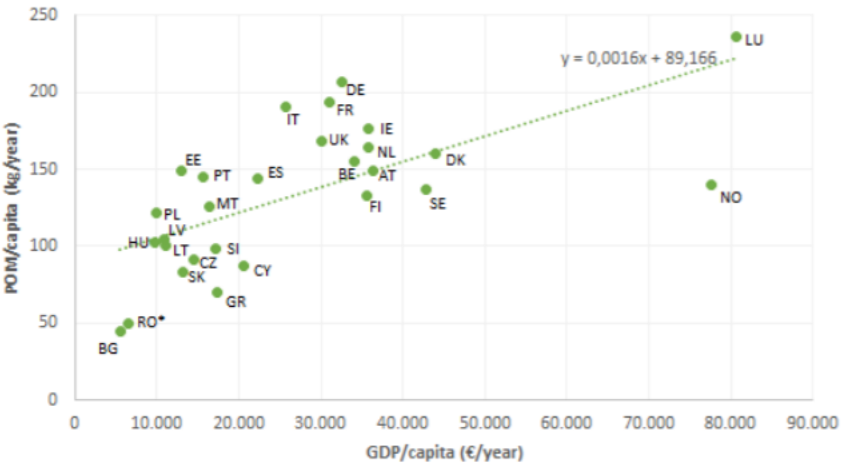


Fig. 66 Correlation between GDP per capita and packaging consumption per capita – Source: EXPRA, 2015

While the statistical relationship between population and packaging consumption is linear, the relationship between GDP and packaging consumption itself demonstrates a certain degree of decoupling. The analysis performed by EXPRA (2015) shows that the higher the GDP per capita is in a country, the more packaging is consumed.

6 SYSTEM DEFINITION IN REGIONAL PLASTIC PACKAGING VALUE CHAIN

6.1 System in plastic packaging field

Components and relations are the main elements characterizing a system. In this case, the main **components** are organizations and institutions where **organisations** are*" formal structures with an explicit purpose and they are consciously created"* while **institutions** are *"sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organisations"* (Edquist and Johnson, 1997).
In plastic packaging value chain, organisations are identified in the framework of stakeholders having any type of relation with plastic packaging. It includes the chemical industry (with reference to oil suppliers, oil processors, oil-re-refiners, chemicals and polymers manufactures), compounders, converters (including designers), brand-owners, users (including consumers), waste collectors and professionals working in waste sorting, recycling, WtE and landfilling plants as well as public authorities such as municipalities, regions and finally, private and public organizations (universities, research institutes, training institutions, standard-setting bodies, local trade associations, regulatory agencies, technology transfer agencies, business associations, relevant government agencies and departments, etc.).
Institutions are defined as the factors influencing the relations between the stakeholders. They mainly include policy, economy, culture, technology, and environmental pressure (See Figure 67).

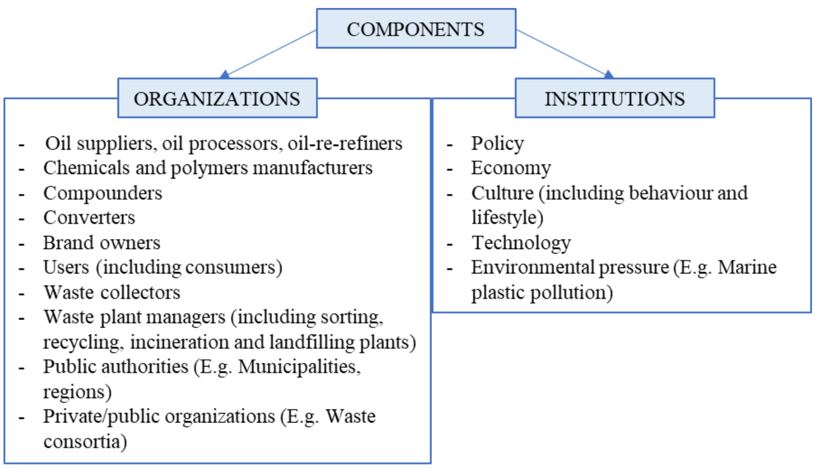


Fig. 67 List of components (organizations and institutions) of the system

As usual, each system is marked by borders. The identification of the borders allows to circumscribe the system from the rest that is named environment (Ingelstam, 2002). As recommended by Edquist (2001), the system should be spatially, sectorally and functionally delimited. Therefore, spatial, sectorial and functional borders have been set.

The following research outlines the system with reference to:

- regional boundaries delimiting EER from the rest
- plastic packaging value chain as the sector of interest
- circular plastic packaging (and in particular the cross-linking between recyclability and effective recycling as well as circularity) as scope to look forward.

The key elements characterizing the system representing the plastic packaging value chain in ERR is illustrated in the figure below where the regional system finds contextualization in the wider plastic value chian.

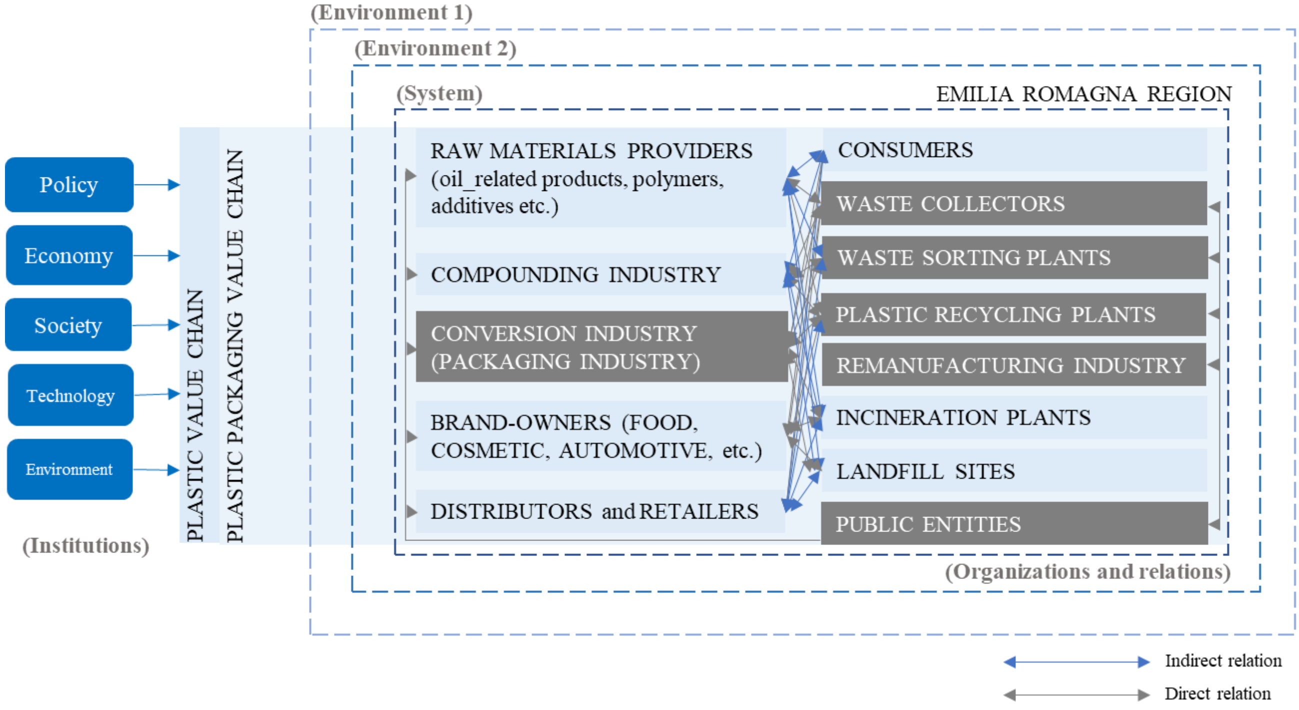


Fig. 68 System definition in plastic packaging value chain

In system innovation, systemic approach is the basis of each interaction. This means that a dynamic process of innovation is established because stakeholders play different roles and influence the process at different level with yielded outcomes (De Vincente et al., 2016). In order to better understand the system and how innovation affects the system, the **activities** should be described and analysed.

As listed by Rickne (2000), the activities should be finalized to:

- create human capital
- develop and diffuse new technology
- experiment and diffuse new products
- provide facilities, equipment and administrative support
- facilitate regulation and provide incentives that may enlarge the market and enhance market knowledge
- enhance networking
- etc.

The activities' analysis helps to identify the determinants of innovation. Through the activities' implementation, different stakeholders are connected. In addition to ordinary activities, organizations perform other activities as results of obligations and pressures provided by the institutions. Moreover, organizations can cooperate to create technological niches, that allow the experimentation of innovation with the co-evolution of technology, user practices, and regulatory structures (Schot and Geels, 2008).

The number of interactions affecting the stakeholders' network and the influence between the system and the environment shows the complexity of the system. However, according the main objective of this work (recyclability and effective recycling of plastic packaging), the system complexity is reduced because of the identification of organization, institutions and relationships that are strictly related to the goal achievement.

6.2 Characterization of the system in Emilia Romagna Region

Because of the fulfilment of a specific final objective, only a certain array of components and relations contribute to the mission. It follows that a critical analysis has been done to allocate organizations and institutions in the right field. In order to better understand the stakeholders, their knowledge, interests and expectations as well as their influence in the innovation process, stakeholders are firstly identified and mapped, then analysed and finally engaged through the participative backcasting method (Kok et al., 2011; Carlsson-Kanyama et al, 2008).

6.2.1 Stakeholders' identification and mapping

The overall stakeholders having a role in plastic packaging value chain are described in the paragraph 3.3. However, in system innovation, the stakeholder identification always refers to the problem or issue to be overcome or address (Lelea et al, 2014).

The **Net Map** has been done to identify the categories of stakeholders that directly or indirectly affect the recyclability and recycling/circularity of plastic packaging.

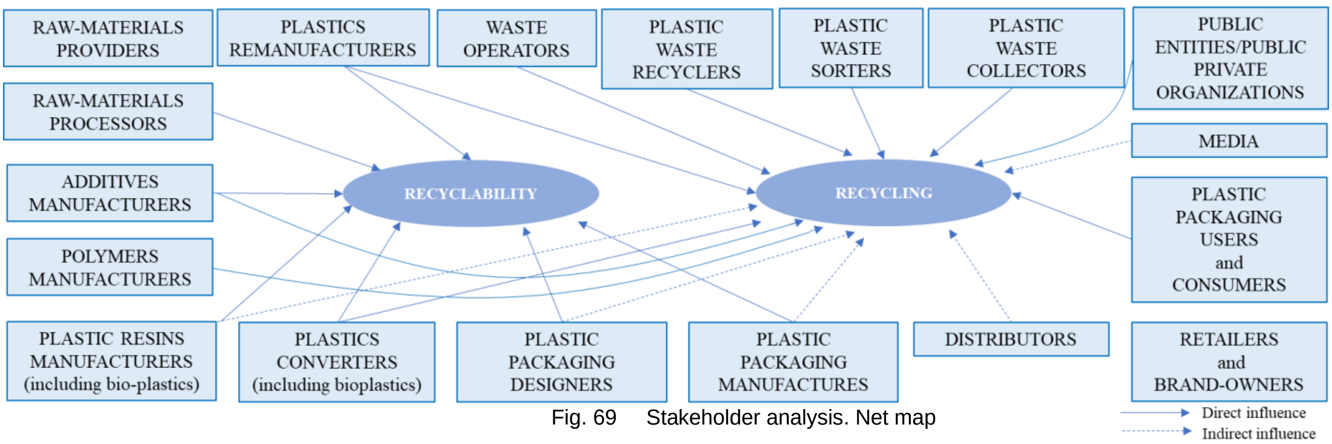


Fig. 69 Stakeholder analysis. Net map

As shown in the figure 69, stakeholders may have direct, direct and indirect, or no influence on recyclability and recycling of plastic packaging. In some cases, stakeholders having a direct impact on recyclability, have consequently an indirect impact on recycling since recyclability and recycling are closely connected.

According to the level of interest and relevance, stakeholders are then mapped onto the **Relevance-Interest Matrix**, to see differences and to find affinity groups or conflictive relationships (De Vincente et al., 2016).

Figure 70 shows exemplarily how the categories of stakeholders are differentiated by their power to influence, modify or tackle the issue in which the project is focused on.

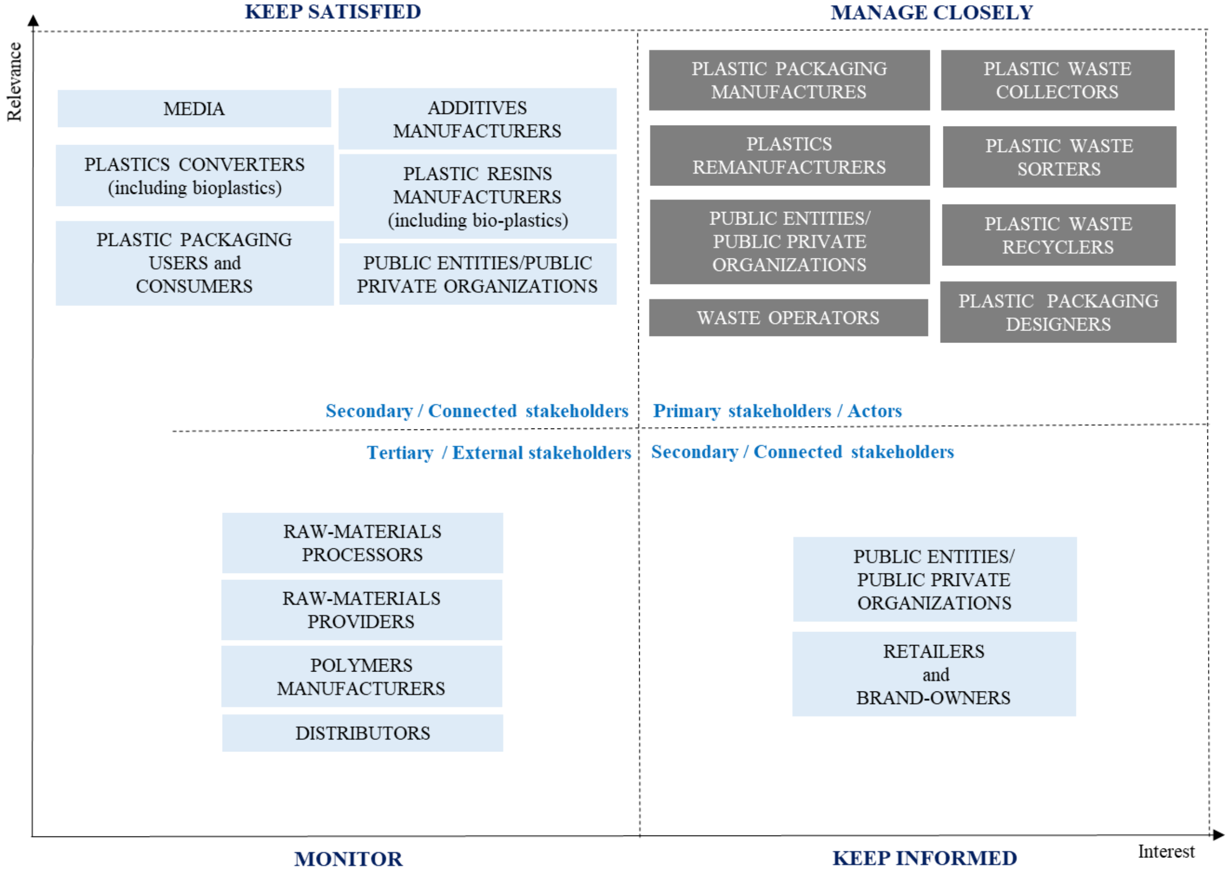


Fig. 70 Strategic stakeholder analysis. Relevance-Interest Matrix

From this graph, it is possible to distinguish:

- **Primary stakeholders** (or **Core Stakeholders** or **Actors**) as stakeholders having an active role and strategic engagement in the system. It includes **facilitating stakeholders** involved in the design, development and maintenance of the system. Facilitating stakeholders may be defined as the pusher and, at the main time, the viewers. It generally includes the policymakers and the framework of organizations supporting the transition towards sustainable production and consumption patterns (Long, 1990).
- **Secondary stakeholders** (or **Connected stakeholders with discrete relevance**) as stakeholders influencing the primary stakeholders or being influenced by primary stakeholders by setting rules or controlling access to a resource or to a market (E.g. government officials or policy makers) (Lelea et al., 2014).
- **Tertiary stakeholders** (or **Connected Stakeholders with discrete interest**) who are directly affected by the success of the failure of the system.

While primary stakeholders cover a pivotal role in implementing the strategy to achieve the final goal, secondary and tertiary stakeholders have a capacity to contribute or to impede the project to various degrees with different impact in terms of relevance and interest (Scholl, 2011).

The following scheme distinguishes the connected and external stakeholders since the firsts affect the success of the project while the second may be indeed affected.

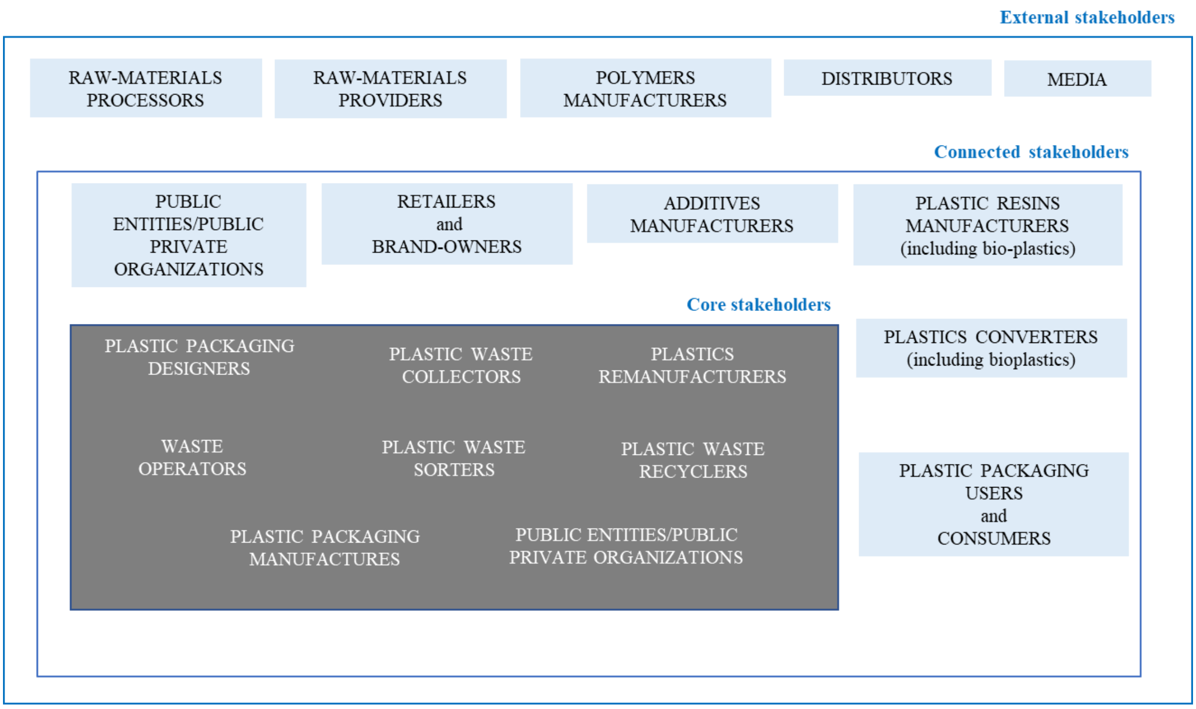


Fig. 71 Map of external, connected and core stakeholders

Stakeholders being assigned to the different quadrants are involved differently in the path of participation process (Zimmermann and Maennling, 2007).

6.2.2 Stakeholders' analysis

6.2.2.1 Analysis of core stakeholders

Stakeholder analysis (SA) is one of the most common approaches for better understand the framework of relations and connections characterizing the system. It supports the understanding of the network before working with it.

Since the core stakeholders may properly contribute to the transition towards a more circular plastic economy, providing a better understanding of the key components (actors), their behaviours and relationships will be the following step of the current analysis (De Vincente et al., 2016).

The Table 25 summarized the basic profiles for the main categories of core stakeholders/actors influencing innovation in the system illustrated in the previous paragraphs.

Tab. 25 Analysis of core stakeholders

	Type of activity (B=Business, PE=Public entity)	Activity	Level of competition	Number	Size
Plastic packaging companies (including packaging designers and manufacturers)	B	Design and manufacture plastic packaging	High	90	Small-medium
Plastic packaging waste collectors	PE (Municipalities)/ B (Multiutilities)	Collect and treat waste	Low	13 multiutilities + 333 municipalities	Medium
Plastic waste sorters	B	Sort plastic waste by polymer and colour	High	42	Small-medium
Recycling plants	B	Reprocess plastic materials into pellets, agglomerates, regrinds etc.	High	52	Small-medium
Waste-to-Energy plants	B	Valorize energetically un-recyclable waste	High	43	Medium
Landfill sites	B	Dispose unrecyclable plastic waste into landfill	Low	10	Small-medium
Plastic packaging remanufacturers	B	Manufacture plastic_based products using recycled polymers	High	Depending on the market	Medium

The previous recognition of stakeholders' framework is then detailed. Each core category is deeply investigated and analysed considering the ERR as spatial frame of examination.

a. Regional plastic packaging industry

Concerning the plastic packaging manufacturing, the regional industry includes **90 companies** (registered through the NACE 22.22.00 and extrapolated from the AIDA database) with a total turnover of 610 billion euros in 2018. The average dimension of that companies is micro and small, the number of medium companies is 13 while only two firms have more than 250 employees. Around 36% of the companies manufactures plastic packaging for food applications.
The biggest firms are:

1) **ILIP S.R.L.**
2) **INFIA S.R.L.**
3) **SOCIETA' GENERALE PER L'IMBALLAGGIO S.P.A. (NES.P.A.K S.P.A.)**
4) **COOPBOX S.P.A.**
5) **SAICA FLEX ITALIA S.P.A.**

The entire list is included in Appendix n.1.

As aforementioned, these companies, together with packaging machinery manufacturing companies are part of the regional Packaging Valley.

b. Plastic packaging waste management industry

As described in the paragraph 3.4.1.1, the Italian waste management system appears to be really complex. Waste and material recovery facilities can be associated to National or Indipendent consortia or work alone in a competitive market.
Summarizing, a framework of National and Independent waste consortia works in the region and manage different type of packaging.
Regarding the national compliance scheme, the Region hosts 14 pre-sorting (CC) and 3 sorting plants (CSS) associated to COREPLA (See Table 26). In 2017, 333 agreements were signed between COREPLA and the municipalities located in ERR (ANCI, 2019). A few companies are also part of the COREPLA's platforms managing specific plastic waste streams.

Tab. 26 List of regional plants associated to COREPLA, 2017 – Source: COREPLA

Name	City	Province	Type of COREPLA infrastructure
AIMAG S.R.L.	Mirandola	MO	CC
APPENNINO AMBIENTE S.R.L.	Val di Sambro	BO	CC
AREA IMPIANTI	Jolanda di Savoia	FE	CC
BANDINI-CASAMENTI SRL	Forlì	FC	CC
CA.RE S.R.L.	Carpi	MO	CC
FINI SERVIZI AMBIENTALI S.R.L.	Zola Pedrosa	BO	CC
HERA S.P.A. BOLOGNA	Granarolo dell'Emilia	BO	CC
HERA S.P.A. CORIANO	Coriano	RN	CC
HERA S.P.A. FERRARA	Ferrara	FE	CC
HERA S.P.A. MODENA	Modena	MO	CC
HERA S.P.A. MORDANO	Mordano	BO	CC
HERA S.P.A. VOLTANA	Voltana	RA	CC
IL SOLCO COOP. SOC.	Savignano sul Rubicone	FC	CC

OPPIMITTI S.R.L.	Parma	PR	CC
ARGECO S.P.A.	Argenta	FE	CSS
IDEALSERVICE CADELBOSCO SOC. COOP.	Cadelbosco di Sopra	RE	CSS
OPPIMITTI COSTRUZIONI/ ENERGY S.R.L.	Bedonia	PR	CSS
CERPLAST S.R.L.	Formigine	MO	PIA
WHITE FOX S.R.L.	Pontenure	PC	PEPS
STARPLASTICK S.R.L.	Parma	PR	PIA
ECO PLAST S.R.L.	Modena	MO	PIA
BANDINI-CASAMENTI S.R.L.	Forli'	FC	PIA
S.A.BA.R. S.P.A.	Novellara	RE	PEPS
SOGLIANO AMBIENTE S.P.A. CERNITA	Sogliano Al Rubicone	FC	PIA
INERTI CAVOZZA S.R.L.	Parma	PR	PIA
GHIRARDI S.R.L.	Parma	PR	PIA
PAGANI ALAN S.R.L.	Monticelli d'Ongina	PC	PEPS
FUSTAMERIA ALBERTAZZI S.N.C.	Castel Guelfo di Bologna	BO	PIFU
ALAN PAGANI	Monticelli d'Ongina	PC	PEPS

While some Independent consortia are being validated, PARI, CONIP and CORIPET, respectively specialized in LDPE, POs and PET packaging recycling, are already operative in many locations in the country.
In the ERR are located:

- 1 of 8 companies working in PARI
- 2 of 26 companies working in CONIP
- 5 of 12[74] companies working with CORIPET

Details are included in the map below.

[74] Considering the overall number of CORIPET members, only few producers are located in the Region. Recyclers work out by the regional borders. Thanks to the increasing rPET market, the introduction of PET bottle collection target and the authorization to operate as Independent consortia received by the Environmental Ministry, CORIPET has quickly increased the number of members, accounting for 34 in 2019.

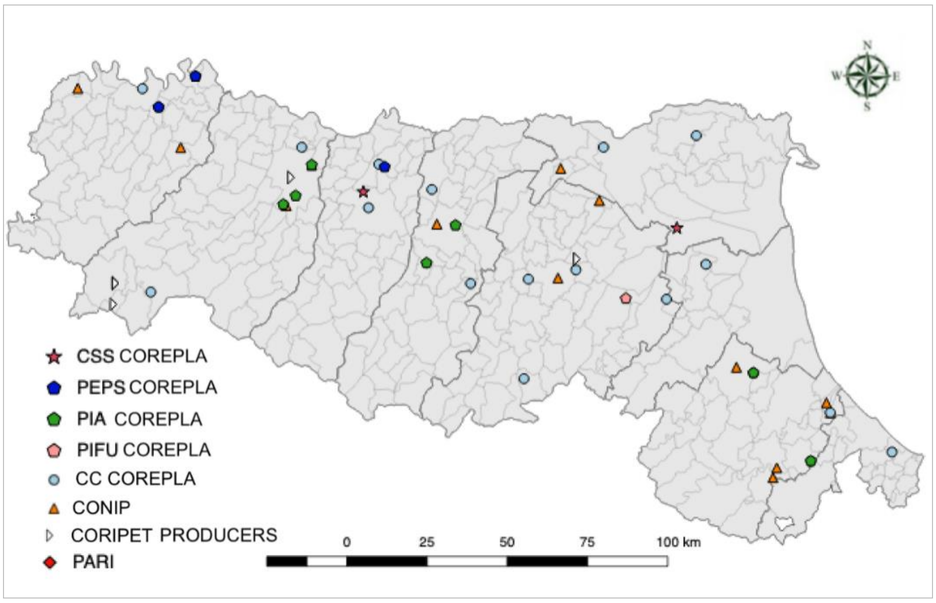


Fig. 72 Map of the regional plants associated to COREPLA, CONIP, CORIPET and PARI

c. Municipal plastic packaging waste collectors in Emilia Romagna Region

The collection (and transportation) of municipal plastic (packaging) waste is managed by the companies whom the regional territorial agency for water and waste services (ATERSIR) entrusts for the management service. Figure 73 shows the main waste management service providers and the area they cover.

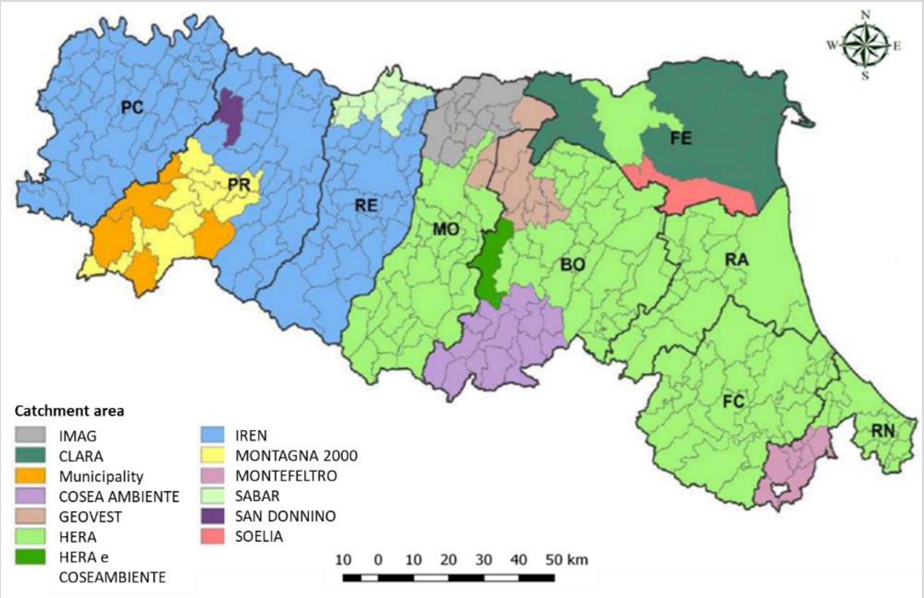


Fig. 73 Catchment regional area servited by the multiutilities in Emilia Romagna Region, 2017 – Source: ARPAE, 2018

As the map (Figure 73) shows, the majority of the territory is served by the multiutilities while only few municipalities in in territory of Parma directly provides the waste collection service. Among the 11 waste collectors, the top 5 list includes:

1) **HERA S.P.A.**
2) **IREN S.P.A.**
3) **MONTEFELTRO SERVIZI S.R.L.**
4) **HERA S.P.A. e COSEA AMBIENTE S.P.A.**
5) **COSEA AMBIENTE S.P.A.**

d. Plastic waste valorization plants in Emilia Romagna Region

When waste enters the MRF, the information about the provenience and origin get lost. It means that packaging plastic waste can be treated together with similar plastic waste[75]. Therefore, the following discussion refers to all the regional plants operating the treatment of plastic waste in general.
The plastic waste management plants are authorized to specific waste treatment as described in the EU Waste Framework Directive 2008/98[76].

The following maps show the localization of waste treatment plants giving also information about the amount of plastic waste handled in 2017.

The complete list is included in the Appendixes n.2,3,4,5.

[75] General plastic waste includes plastic wastes resulting from agriculture (EWC 020104), automotive (EWC 160109), plastic (EWC 120105) and waste (EWC 191204) industries as well as municipal plastic waste (EWC 150102), included assimilated/similar plastic waste (EWC 200139) coming from commercial and economic activities.
[76] As shown in the table below, the waste recycling activities are classified through European codes.

Tab. c. European waste treatment codes

CODE	SUBCODE	Primary Activity	Description	Details
R3	R03.01.01 R03.01.02 R03.01.03 R03.01.04 R03.01.05 R03.01.06 R03.01.07	Bulking up organic wastes	Paper Plastic Wood Green/garden waste Kitchen/garden waste Clothing/textiles Wood/plastic/textile furniture	Transfer activities for specific waste streams that are recovered but are NOT mixed waste streams.
R4	R04.01.01 R04.01.02	Bulking up metals	Metal packaging waste i.e. cans Other metals	Transfer activities for specific metallic waste streams that are recovered NOT mixed waste streams
R5	R05.01.01	Bulking up glass	Glass	Transfer activities for glass that is recovered but NOT in a mixed waste stream.
R12	R12	Waste transfer for recovery	Exchange of wastes for submission to any other recovery operation numbered R1 to R10 (transfer station for recovery operations other than for R3 to R5)	Transfer of wastes to any recovery operation R1 to R10 (other than R3 to R5).
R13	R13	Temporary storage	Temporary storage of wastes pending any other recovery operation (excluding temporary storage, pending collection, on the site where it is produced).	

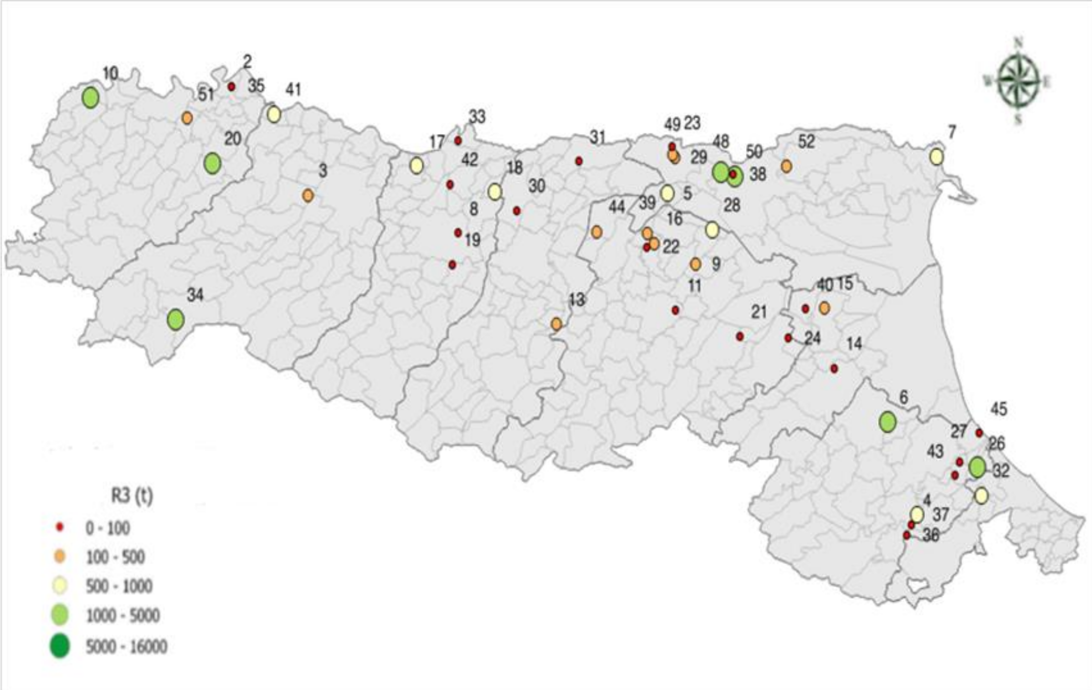


Fig. 74 Regional plants, code R3. Analysis per total waste managed in 2017

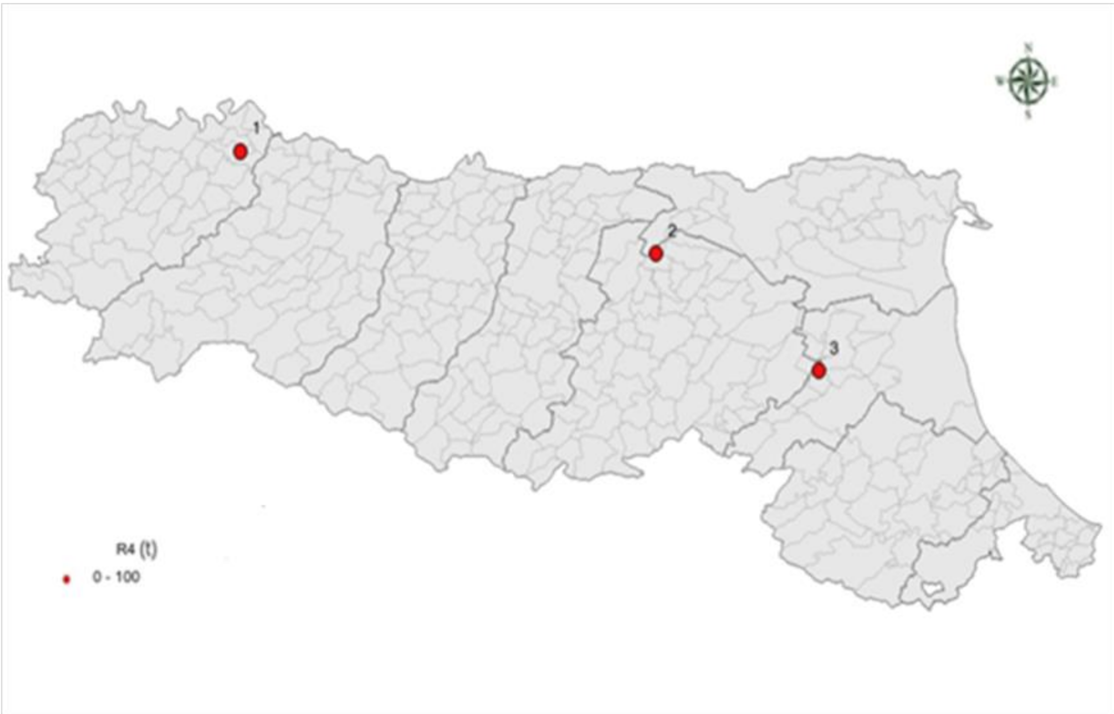


Fig. 75 Regional plants, code R4. Analysis per total waste managed in 2017

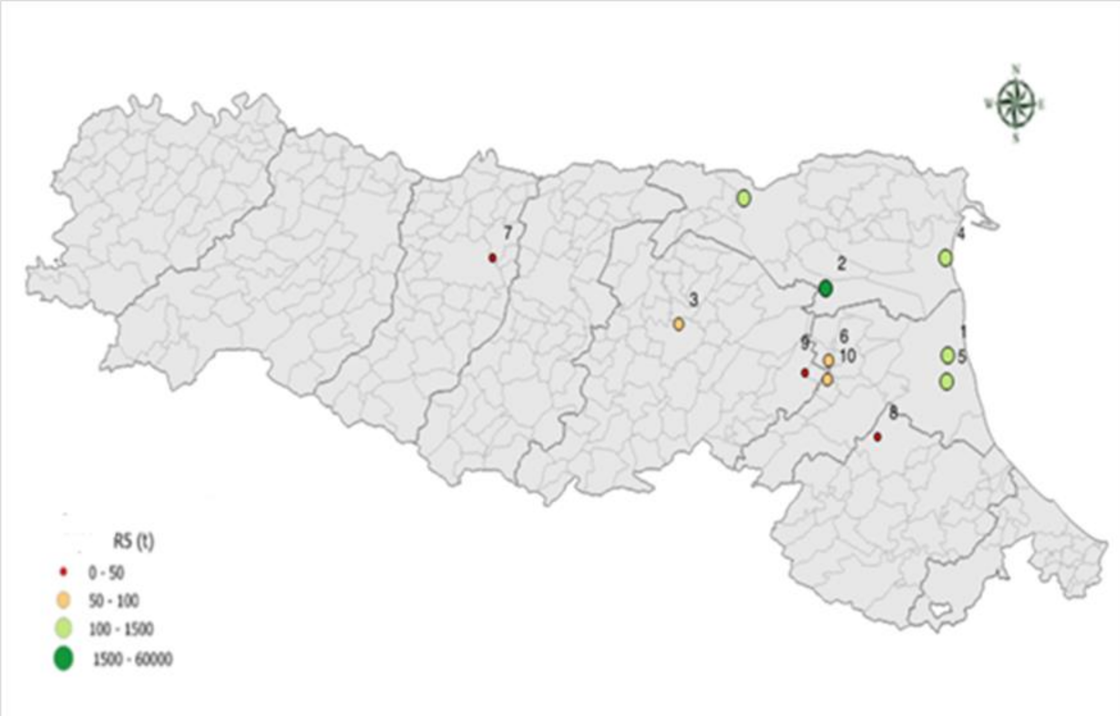


Fig. 76 Regional plants, code R5. Analysis per total waste managed in 2017

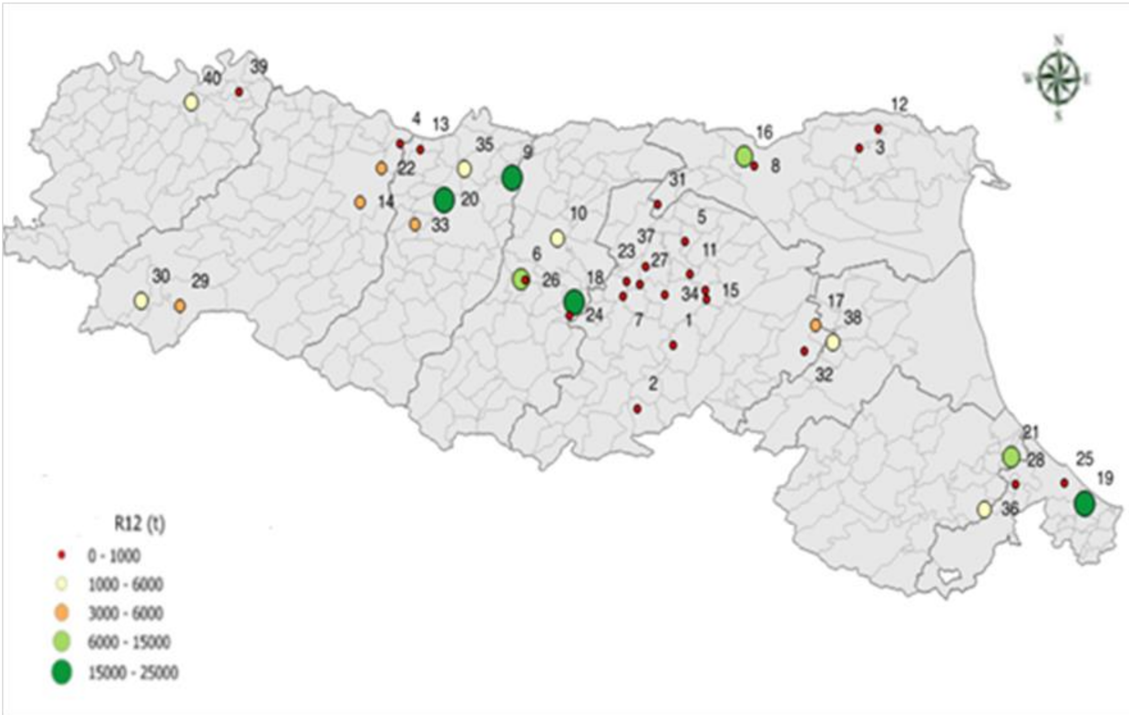


Fig. 77 Regional plants, code R12. Analysis per total waste managed in 2017

The biggest plants are listed below[77].

In particular, the province of Ferrara hosts the biggest regional plants working on the material valorization, such as:

1) **Argeco S.P.A.** (18,6% - R5),
2) **A.M.P. Recyclcing S.P.A.** (2,7% - R3)
3) **HeraAmbiente S.P.A**. – Ferrara (2% - R12)
4) **Petra Polimeri S.R.L.** (1,9% - R3)
5) **Unirecuperi S.R.L.** (1,2% - R3 and R5)[78]

In the provice of Reggio Emilia, three main plants are located:

1) **Idealservice COOP. SOC.** (12,8 % - R12)
2) **De Paauw Recycling Italia S.R.L**. (4,9% - R12)
3) **S.a.ba.r. S.P.A.** (1,9% - R12 and, on a smaller scale R3)[79]

In the province of Modena, the plastic wastes are handled by the following plants:

1) **CA.RE. S.R.L.** (3,9% - R3)
2) **CERPLAST S.R.L.** (2,6% - R12)
3) **HeraAmbiente S.P.A.** – Modena (1,3% - R12)
4) **Ecoplast S.R.L.** (1% - R12)[80]

In the province of Parma are located:

1) **Oppimitty Energy S.R.L.** (8,8% - R12)
2) **Società Europea Rigenerazione S.R.L.** (5,3% - R3)
3) **Oppimitty Costruzioni S.R.L.** (3,3% - R12)
4) **Starplastick S.R.L.** (1,6% - R3)[81]

The area of Rimini hosts **HeraAmbiente S.P.A. – Coriano** working around l'1,8% (R12) of total waste managed in the region. **HeraAmbiente S.P.A. – Voltana** (2,7% - R3) treats plastic waste in the area of Ravenna. **HeraAmbiente S.P.A. – Bologna** works the plastic wastes in the plant located in Granarolo (near Bologna) (6,5% - R12).

In the province of Forlì-Cesena, two small plants are located:

1) **Sogliano Ambiente S.P.A.** (1,5% - R12)
2) **Bandini-Casamenti S.R.L.** (1% - R3)[82]

Finally, in the province of Piacenza there are:

1) **White Fox S.R.L.** (1,7% - R12 and, on a smaller scale R3)
2) **Forplast S.R.L.** (1,3% - R3)[83].

There are no chemical recycling plants in the region.

[77] Data refers to 2017. The analysis is done per province.
[78] The remaining is lower than 1% of the total regional plastic waste.
[79] The remaining is lower than 1% of the total regional plastic waste.
[80] The remaining is lower than 1% of the total regional plastic waste.
[81] The remaining is lower than 1% of the total regional plastic waste.
[82] The remaining is lower than 1% of the total regional plastic waste.
[83] The remaining is lower than 1% of the total regional plastic waste.

e. Other waste plants in Emilia Romagna Region

Even if recycling is the core of this work, scraps and wastes resulting from the process of recovery materials are sent to incineration or WtE plants as well as landfill sites. Since waste disposed of to landfill are preliminary treated to valorize metals and glasses and stabilize the biodegradable component of the material, many waste processing facilities operating the mechanical biological treatment (MBT) exist.
In particular, the region hosts:

- 11 incineration plants
- 43 WtE plants
- 10 landfill sites
- 8 MBT plants

Although not closely connected to the plastic waste disposal, many storage sites, plant operating the chemical-physical treatments and composting facilities and other waste_related facilities are present in the region.

6.2.2.2 Analysis of facilitating stakeholders

As already mentioned, facilitating stakeholders are categorized as stakeholders who provide the instruments to achieve the final goals. This category generally includes the policymakers and the framework of organizations supporting policy, economic and financial instruments as well organizational issues (Long, 1990).
As illustrated in the previous chapter, the following study aims to transpose the EU legislation on plastics circularity into a regional dimension in order to achieve the targets about having 100% recyclable plastic packaging and 55% plastic packaging recycling rate by 2030. As previously described, the exploration and exploitation space is identified in the ERR and in particular in the regional stakeholders working in plastic packaging value chain. However, the system is influenced by the environment.
The connection between the system and the surrounding environment led to identify facilitating stakeholders:

- at regional level as policy and decision makers fostering innovation in the regional context
- at national and EU level as inspiring as well as supporting stakeholders helping in decision-making process

Al already illustrated in the Figure 71, facilitating stakeholders work both in the system and the environment because of the open connection between the two spaces.

Many institutions, organizations and associations are active in plastic packaging recyclability, recycling and generally, circularity. The following tables (Tables 27,28,29) introduce a list of facilitating stakeholders respectively working at EU, national and regional level. Each institution, organization and association has been investigated to identify those who may directly contribute to the research.

Tab. 27 Analysis of facilitating stakeholders, European dimension

	Acronym	Type of entity				Functions	Connection to the research (D=direct; I=indirect)
		Government	Organization	Association	Alliance		
DG Environment - EU Commission	DG Env - EC	■				Propose policies and legislation that protect natural habitats, keep air and water clean, ensure proper waste disposal, improve knowledge about toxic chemicals, and help businesses move towards a sustainable economy	D
EU Chemical Agency	ECHA	■				Implement EU's ground-breaking chemicals legislation	I
EU Food Safety Authority	EFSA	■				monitor and analyse information and data on biological hazards, chemical contaminants, food consumption and emerging risks according to priorities agreed with the EC	I
Extender Producer Responsibility Association	EXPRA			■	■	Optimize the packaging waste recovery and recycling systems	D
European Organization for Packaging and the Environment	EUROPEN		■			Conveys expert information, data, opinions and policy options to its members and EU policy stakeholders about the environmental, economic and social aspects of sourcing, manufacturing, marketing, distribution and end-of-life of packaging and packaged products	I
Flexible Packaging Europe	FPE			■		Provide information to the authorities about the European flexible packaging industry to help and facilitate legislation	I
Pack2Go	Pack2Go			■		Promote CE on companies that manufacture packaging for the food and beverages consumed on-the-go	I
Packaging Recovery Organisation Europe	PRO Europe		■			Give the licenses for the licensor of the Green Dot trademark to EU packaging and packaging waste recovery and recycling operators	I
PlasticsEurope	/			■		Collect EU data on plastics production, consumption and disposal and enable solutions on circularity and resource efficiency among plastics manufacturers, converters, recyclers as well as machinery manufacturers	I
European Plastics Converters	EUPC			■		Support market development, regulation, issue management and trade for EU packaging converters	I
Plastics Recyclers Europe	PRE			■		Support EU recyclers to improve recycling efficiency by providing tools and certifications	D
European Plastics and Rubber Machinery	EUROMAP			■		Provide technical recommendations highlighting state-of-the-art technological requirements and perform market analysis on the plastics and rubber machinery industry	I
Circular Plastics Alliance	/				■	Deliver the CE for plastics and substantially increase the use of recycled plastics into new products	I
Alliance to End of Plastic Waste	/				■	Invest $1.5 billion over the next five years to properly collect and manage waste and increase recycling by innovative technologies implementation and education activities	I
Rethink Plastics Alliance	/				■	Bring together policy and technical expertise from a variety of relevant fields, and work with European policy-makers to design and deliver policy solutions	I

Tab. 28 Analysis of facilitating stakeholders, national dimension

		Type of entity				Functions	Connection to the research (D=direct; I=indirect, /= no connection)
	Acronym	Government	Organization	Association	Other		
DG Waste and pollution, Ministry of Environment	DG RIN, MinAmb	■				Implement environmental policy	D
Italian Institute for Environmental Protection and Research	ISPRA				■	Collect and elaborate official data on air pollution, waste management and general issues concerning the environment protection	D
National Packaging Consortium	CONAI				■	Coordinate the management and financial system of separate waste collection and packaging waste recycling	D
National Association of Italian Municipalities	ANCI			■		Manage all the activities concerning the municipalities' interests, lobbying parliament, the government, regions, and Italian public administration and EU bodies	D
National plastic packaging waste consortium	COREPLA				■	Coordinate the management and financial system of separate waste collection and plastic packaging waste recycling	D
National Independent consortium for PET bottles	CORIPET				■	Implement selective collection for food-grade PET bottles through eco-compacters and recycle them in closed-loop process	I
National Indipendent Plastic Packaging Consortium	CONIP				■	Organize and promote the collection of secondary and tertiary plastic packaging from private areas and recycle them	I
Independent consortium for LDPE flexible packaging	PARI				■	Organize and promote the collection of LDPE flexible packaging from private areas and recycle them	I
Rubber-plastic Federation	/				■	Support national plastic and rubber industry through consulting and training activities	I
National association of waste sorting plants	ASSOSELE			■		Regulate the relationship between the CSSs and COREPLA	D
National association of recycling plants	ASSORIMAP			■		Give legislative support to plastic waste recyclers	D

Tab. 29 Analysis of facilitating stakeholders, regional dimension

		Type of entity				Functions	Connection to the research (D=direct; I=indirect)
	Acronym	Government	Organization	Association	Other		
DG Environment, Emilia Romagna Region	DG ENV, ERR	■				Make integrated actions and specific plans focused on air quality, agriculture, energy, mobility, waste management, protected areas, Natura 2000 Network, forests and education to sustainability	D
DG Economy, Emilia Romagna Region	DG EC, ERR	■				Support regional economic activities through structural funds in order to promote enrgy policies, green economy, industrial research, innovation and technology transfers well as tourism and other sectors	D
Regional Agency for Prevention, Environment and Energy of Emilia-Romagna	ARPAE				■	Collect and elaborate official data on air pollution, waste management and general issues concerning the environment protection at regional level	D

It follows that the facilitating actors having a possible strong contribution in the strategy implementation are:

- DG Environment of EC
- DG RIN of MinAmb
- DG Environment and Economy of ERR
- EXPRA
- ANCI
- CONAI and COREPLA (including ASSOSELE, ASSORIMAP)
- PLASTICSEUROPE and PLASTICSRECYCLERSEUROPE
- ISPRA
- ARPAE

6.2.2.3 Network stakeholder analysis

From a systemic approach, the most important step when studying stakeholders is to map out the relations among them and analyse the network they form. When the future is already envisioned, the relationship among stakeholders allows to better define the average degree of separation within groups and the cross-group connectivity. In particular, the actors (including the facilitating ones, as identified in the paragraph 6.2.2.2) are deeply analysed to capture the value they may offer for the implementation of the final research goal.

The following table summarizes the function fulfilled by each actor towards plastics recyclability and recycling.

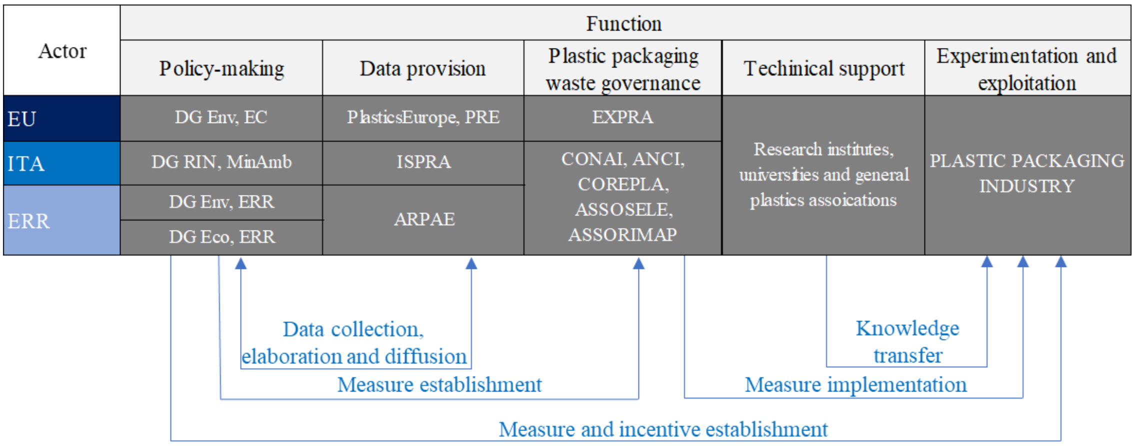


Fig. 78 Network stakeholder analysis

6.2.2.4 Stakeholder engagement: the participative backcasting formula

Stakeholder network engagement is the process of carrying out the engagement itself, with the envisaged activities involving actors throughout the whole process of transition. One of the main differences that stands out in the socio-technical transition approach from other perspectives is the dynamic character of the analysis. Sociotechnical transition is an on-going and living process: the participants in such a process and their roles should be analysed more than once (De Vincente et al., 2016). The partecipative process is aimed to:

- analyse people preference,
- identify possible measure to reach the envisioned future
- stimulate learning process
- encourage cross-value -chain involvement (Soliva et al., 2008; Forsyth and Brooks, 2011)

In this research, actors have been engaged to have a deeper knowledge about problems and needs at first and to co-create possible solutions then.

The participative process has been running since 2018. It has been performed by using different approaches and tools in accordance to the level of implementation of the process (See Tab 30).

Tab. 30 Summary of participative process activities

Actor	Activity	Tool	Issue	Objective	Results
PLASTIC CONVERTERS	A	Survey	Usage of post-consumer recycled plastics	Barriers affecting the use of post-consumer recycled plastics	Micro-level barriers analysis
PLASTIC RECYCLERS	B	Questionnaire	Plastics recycling	Plastics recycling throughput	Quantitative material analysis on plastic waste stream
POLICY MAKERS	C	Interview	Legislative measures on plastics	Strategic policy setting up and planning	Micro-level barriers analysis
ALL	D	Match-making workshop	Connection between policy and industry	Efficient supporting policy and instrument	Meso-level barriers analysis and problem orientation

While the tools A and B aimed to investigate the state of art of CE practices in the region, the tool C supported the understanding of policy-makers viewpoint. The match-making workshop has been organized to integrate different problems and needs in order to support the problem orientation and the strategy planning.

The details of each initiative are reported in the Appendixes n.6,7,8,9.

Preliminary results about interests and challenges affecting each category have been summarized in the following table.

Tab. 31 Summary of participative process results

Actor	Interests and targets	Challenges
PLASTIC CONVERTERS	Green marketing, waste management cost reduction (EPR), sustainable corporate agenda development	Recyclability of plastic packaging and inclusion of post-consumer recycled plastics content in new product manufacturing
PLASTIC RECYCLERS	Process optimization, stable supply chain, profit maximization, cost reduction, secondary plastics price stability	High-quality of secondary plastics
POLICY MAKERS	Efficient policy and measures	Recyclability and recycling metrics
ALL	Competitive and profitable packaging valley	Efficient after-use plastics economy

The specifications are included in the following paragraphs by supporting the depiction of:

- the quantitative analysis of plastic packaging goods and waste (See paragraph 7.1)
- the quantitative analysis of PCR plastics (See paragraph 7.2.1)
- the qualitative analysis (See paragraph 7.3)
- the problem orientation (See paragraph 7.4)

7 REGIONAL PLASTIC PACKAGING SYSTEM KNOWLEDGE

This step of the backcasting process concerns the present time investigation with the aim to examine each factor as well as problem or challenge the study are facing on.

The investigation is carried on:

- At quantitative level, through a MFA
- At qualitative level, through MLP barriers analysis (including PESTEL and SWOT analysis)

7.1 Plastic flow through in Emilia Romagna Region

The following scheme summarizes the flow through for plastic packaging and PPW (including the Assimilated/Similar waste) managed in ERR in accordance to the present governance and waste management structure.

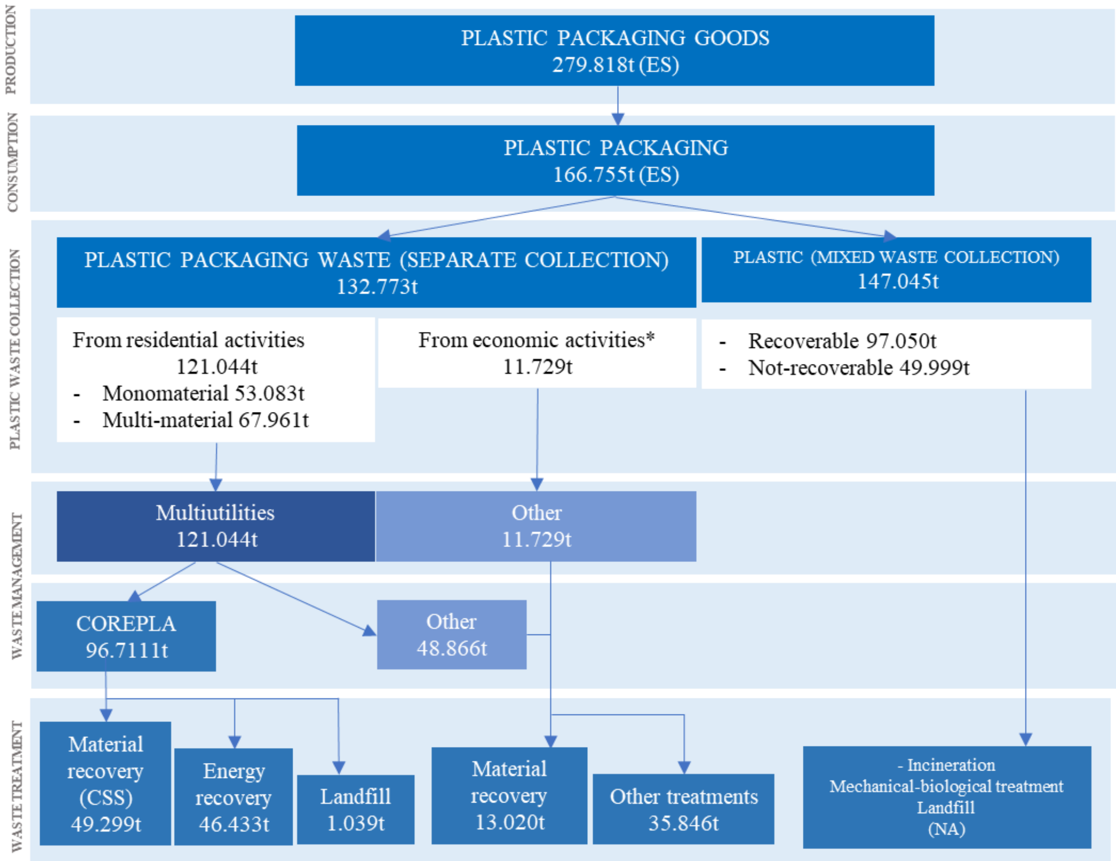


Fig. 79 Flow through for municipal plastic packaging and plastic packaging waste in Emilia Romagna Region, 2017. *=Similar/assimilated waste; NA=Not-available; ES=Estimation – Source: MUD database

About primary management of MPPW, 76% of MPPW stream are sent to recovery (See Figure 79). Public waste operators managed 91% of the overall amount of PPW separately collected in the Region (corresponding to 121.044t). 96.711t of separately collected PPW (corresponding to 70%) were managed by COREPLA through a framework of CCs and CSSs. Regarding the waste shipment, about 70% (67.700t) of

the overall waste collected by separate scheme was sent to plants located in the Region (3 CSSs) while the remains (29.171t) were treated outside the regional boundaries in 9 CSSs. The plastic wastes sorted by the CSSs are then sold through electronic auctions to an EU market. COREPLA sent to recycling around 49.299t of plastics in 2017.
The total amount of regional MPPW sent to recycling and disposal respectively accounted for 62.319t and 70.454t in 2017. It follows that less than half amount of plastic packaging consumed in 2017 are materially recovered.

Regarding the overall plastic goods, it is not possible to track the entire MFA because of the presence of multi-composite products in one side and the lack of official dataset in another. The following scheme summarizes the available information regarding the other plastic waste generated and managed in ERR in 2017.

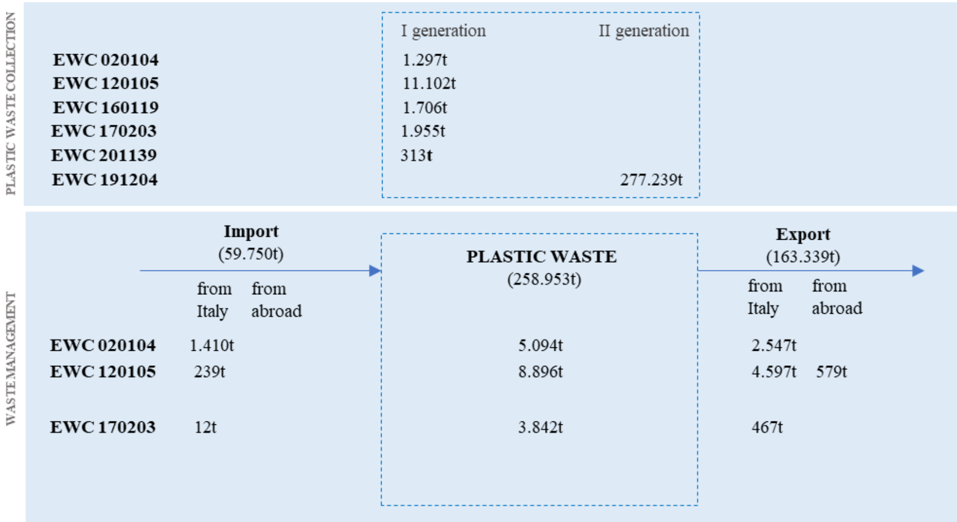


Fig. 80 Flow through for special plastic waste, 2017. Analysis per European Waste Code – Source: MUD database

Particular attention should be paid to the EWC 191204 that groups plastic waste generated by the waste treatment plants. It means that the packaging waste categorized by the EWC 150102 and 200139 may change the codification after a preliminary treatment; however, it is not possible identify the origin of the plastic wastes included in the EWC 191204.

7.1.1 Plastic packaging goods production

Because of the short life span of plastic packaging goods, article 2 of the European Decision 2005/270/EC establishes that the "*packaging waste generated in a MS may be deemed to be equal to the amount of packaging placed on the market in the same year within that MS"* (European Parliament and of the Council, 2005). It follows that the amount of plastic packaging placed on the market in 2017 was equal to the amount of plastic packaging collected in the same year; therefore, the total amount of plastic packaging placed on the market was 279.818t[84] in 2017.

[84] The number comes from the sum of plastic packaging collected in separated and mixed waste bins.

7.1.2 Plastic packaging consumption

The overall amount of plastic packaging consumed in the region is un-known. According to the national consumption, taking into account the regional inhabitants, the plastic packaging consumption ahs been estimated at 166.755t in 2017.

7.1.3 Plastic waste generation (including packaging waste)

Considering the overall amount of plastic waste, municipal plastic waste, (and consequently PPW) represents 27,7% of the overall plastic waste stream collected in the region as registered in official data[85].

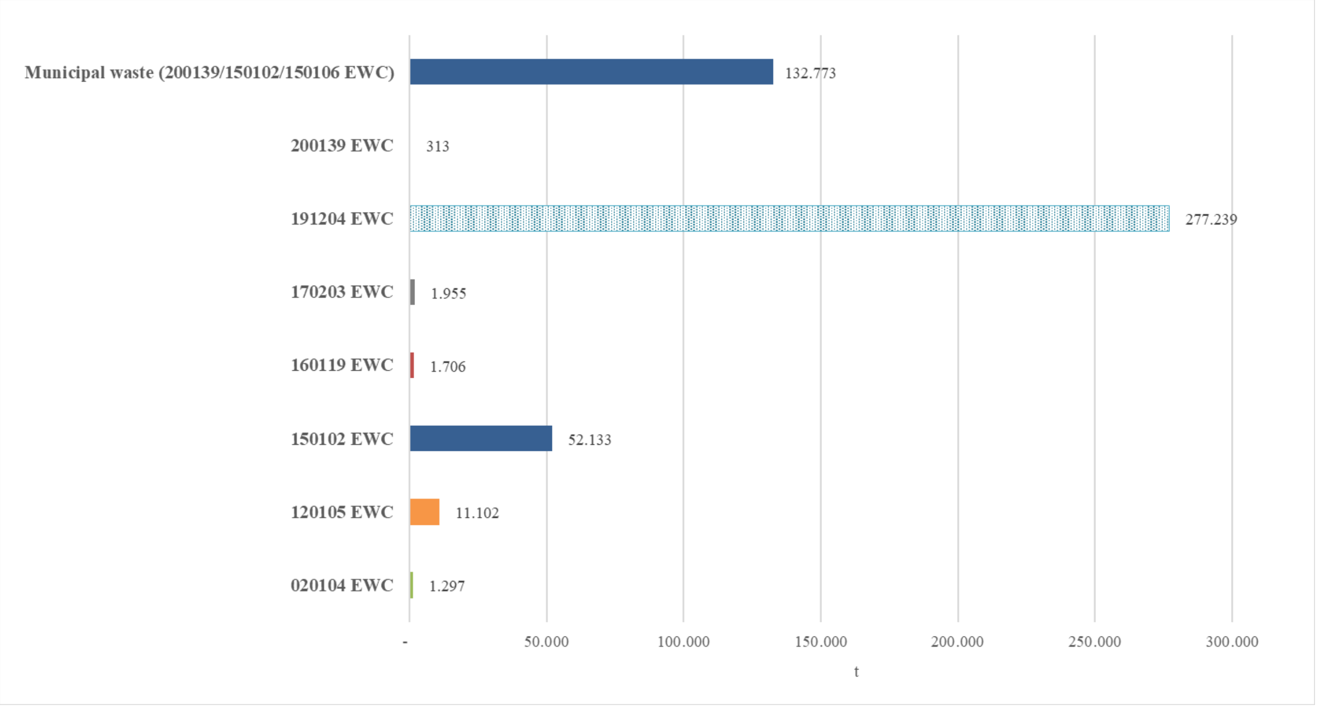


Fig. 81 Generation of plastic waste in Emilia Romagna Region, 2017. Analysis per European Waste Code – Source: ORSo and MUD databases

[85] The overall amount of plastic waste refers to both municipal and special waste. According to the European Waste classification, municipal wastes are classified by the European waste codes (EWCs) 150102 and 200139. The EWC 191204 classifies plastic scraps generated during the recycling process.

EWC	Description
120105	Plastics shavings and turnings coming from shaping and physical and mechanical surface treatment of metals and plastics
020104	Plastics (except packaging) coming from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing
150102	Plastic packaging (including separately collected municipal packaging waste)
150106	Mix of packaging (collected through municipal waste collection scheme)
160119	Plastics coming from end-of-life vehicles from different means of transport (including off-road machinery) and wastes from dismantling of end-of-life vehicles and vehicle maintenance (except 13, 14, 16 06 and 16 08)
170203	Plastics coming from construction and demolition wastes (including excavated soil from contaminated sites)
191204	Plastics and rubber coming from wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising) not otherwise specified
200139	Plastics coming from municipal waste collection (household waste and similar commercial, industrial and institutional wastes), including separately collected fractions

The municipal waste includes household plastic packaging waste (150102 EWC), and an amount of packaging waste generated by industrial and commercial activities and collected through separated waste collection scheme (the so-called Similar/Assimilated waste, collected through the official scheme for household waste) accounted for 11.729t in 2017. The household mix packaging (150106 EWC) are also included in the generation stage.

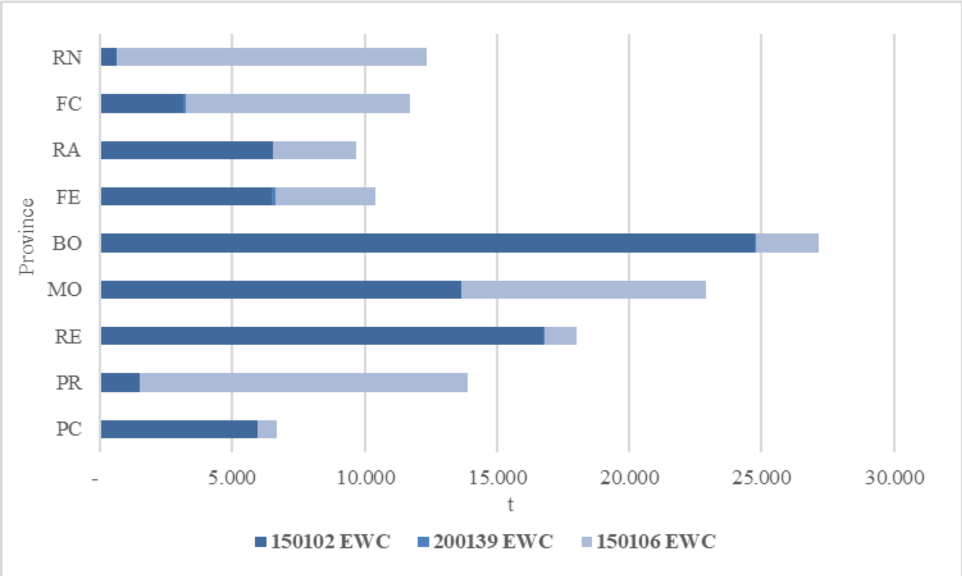


Fig. 82 Generation of municipal plastic packaging waste in Emilia Romagna Region, 2017. Analysis by province. - Source: ORSo database

Referring to the generation by province, Rimini (RN), Bologna (BO), Ferrara (FE) and Parma (PR) registered the highest amount of plastic waste (per capita) in 2017.

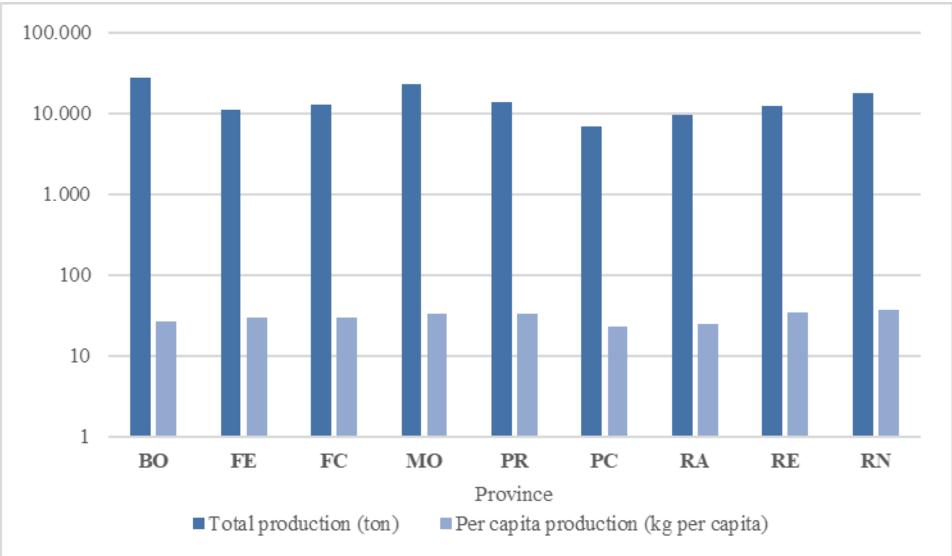


Fig. 83 Generation of municipal plastic packaging waste in Emilia Romagna Region, 2017 - Source: ORSo database

Since the EWC191204 covers a particular function in tracking the plastic waste stream, the graph showing the generation of special waste is here reported.

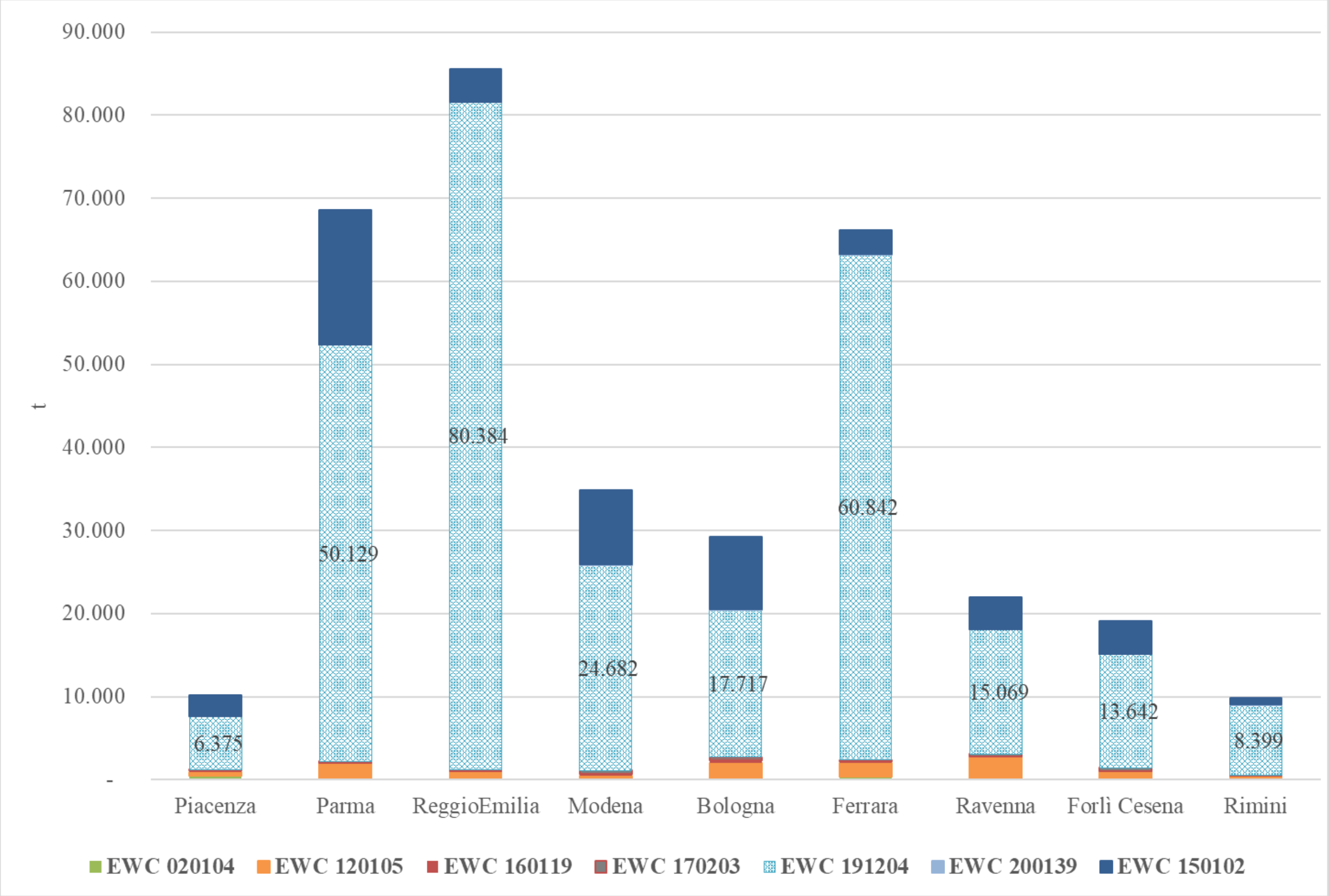


Fig. 84 Generation of special plastic waste in Emilia Romagna, 2017 – Source: MUD database

7.1.3.1 Municipal plastic packaging waste collection

On a regional scale, the amount of PPW disposed of by separate collection scheme accounted for 47% (132.773t, corresponding to 30kg per inhabitant) in 2017.

As for collection systems, 40% of the plastic was collected together with other waste in the multi-material collection. The most widespread system includes road bins, followed by door-to-door or home collection (See Figure 85).

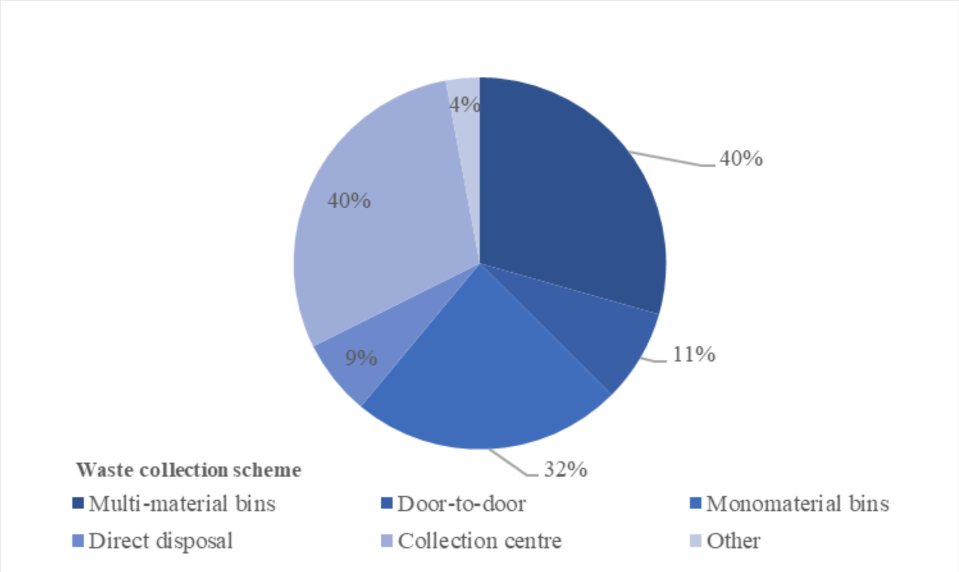


Fig. 85 Collection of municipal plastic packaging waste in Emilia Romagna Region, 2017. Analysis by type of collection scheme - Source: ARPAE, 2018

However, plastic collected by separated bins represents only 47,5%. The remaining amount has been collected in bins for mixed waste: 34,7% of plastic waste found in the mixed waste stream is defined by ARPAE as potentially recoverable, if correctly separated (ARPAE, 2018).

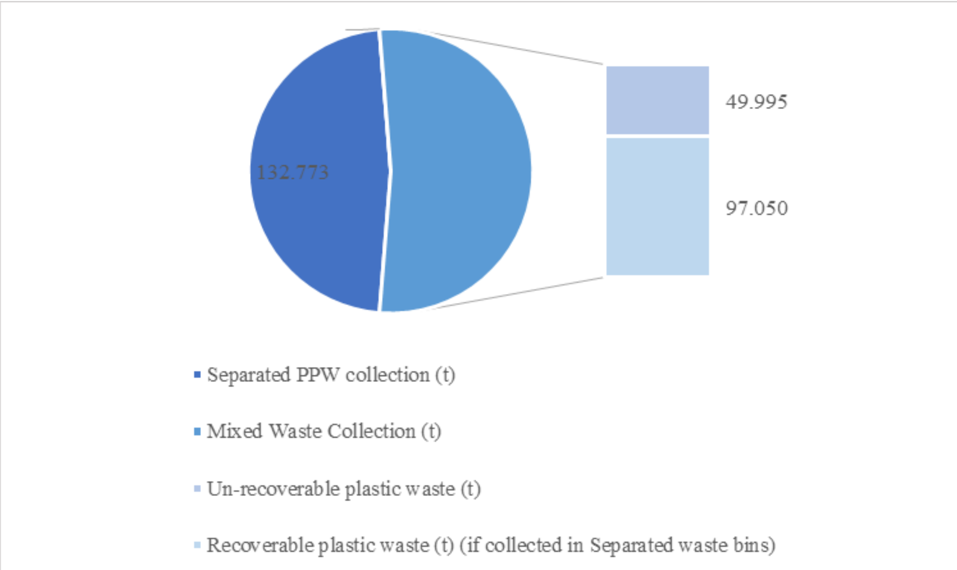


Fig. 86 Analysis of plastic stream in mixed waste collection – Source: ARPAE, 2018

7.1.4 Plastic waste treatment (including packaging waste)

As cited in the paragraph 3.3.2, when wastes are treated in the facilities, the information about the origin and provinces get lost. It follows that the management refers to all plastic waste handled in the region.

The following graph shows the overview of treatments done to the plastic waste streams managed in the region[86] [87].

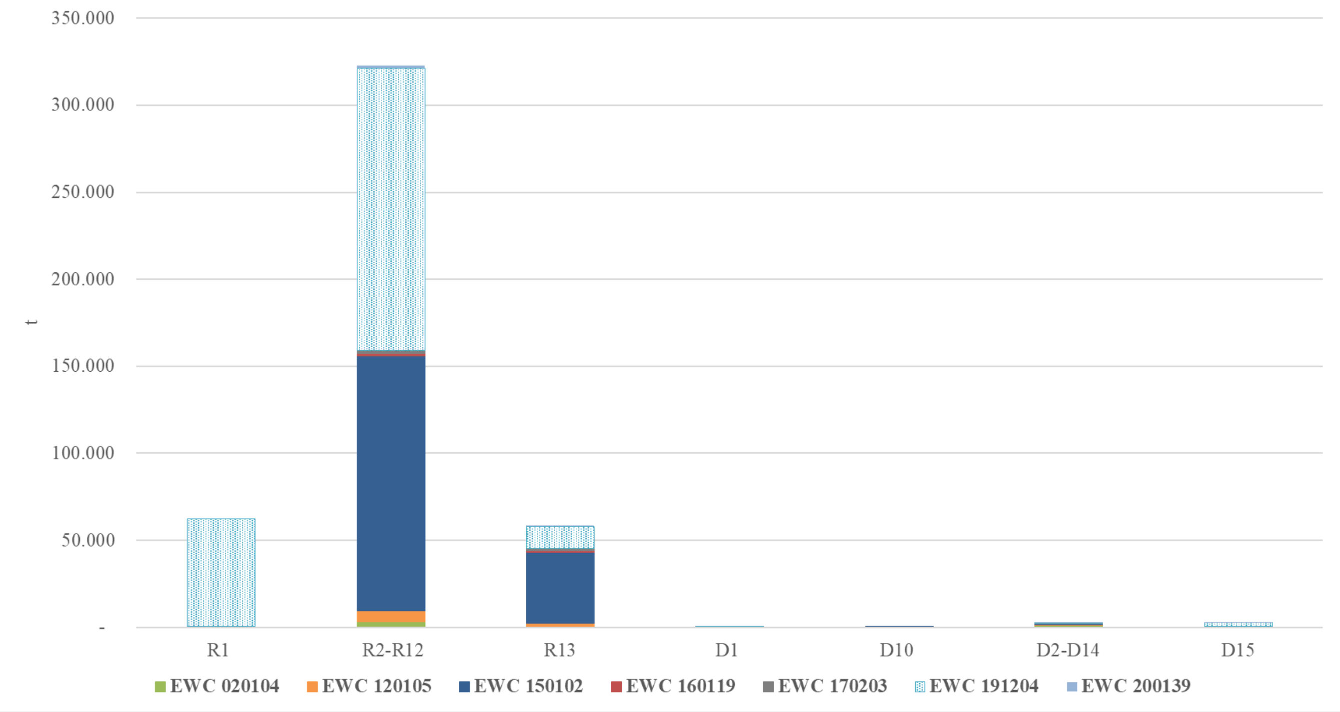
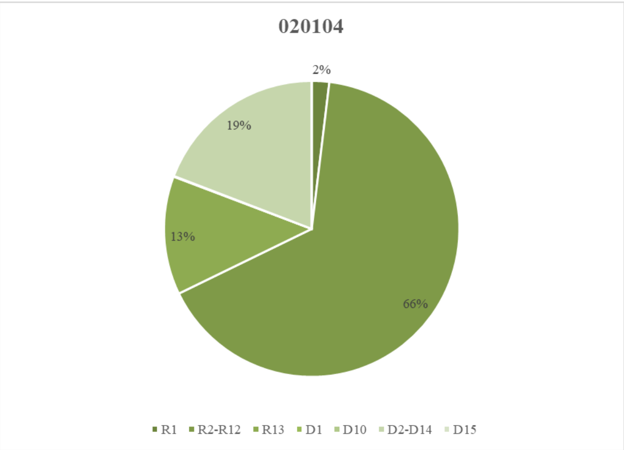
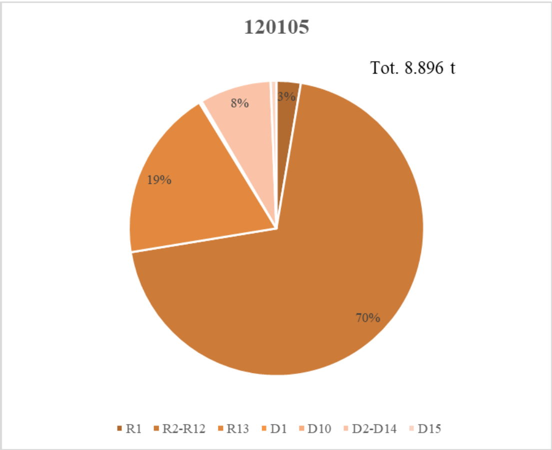


Fig. 87 Treatment of plastic waste in Emilia Romagna Region, 2017 – Source: MUD database

Focusing the analysis on material valorization (R2-R12) and energy recovery (R1), the following graph points out the amount of waste sent to recycling and incineration plants in Emilia Romagna Region in 2017. The two waste streams considered by this study (EWC 150102, 200139 and EWC 191204 as waste coming from the treatment of the first two waste streams) have the higher contribution to the recovery performance.





[86] It refers to the overall plastic waste managed in the region (not only those managed by COREPLA).

[87] The analysis of bioplastics is not included in this work because the management of bioplastics that are biodegradable and compostable (according to the UNI EN 13432) is carried on by the National Consortium of Composting Plants (CIC).

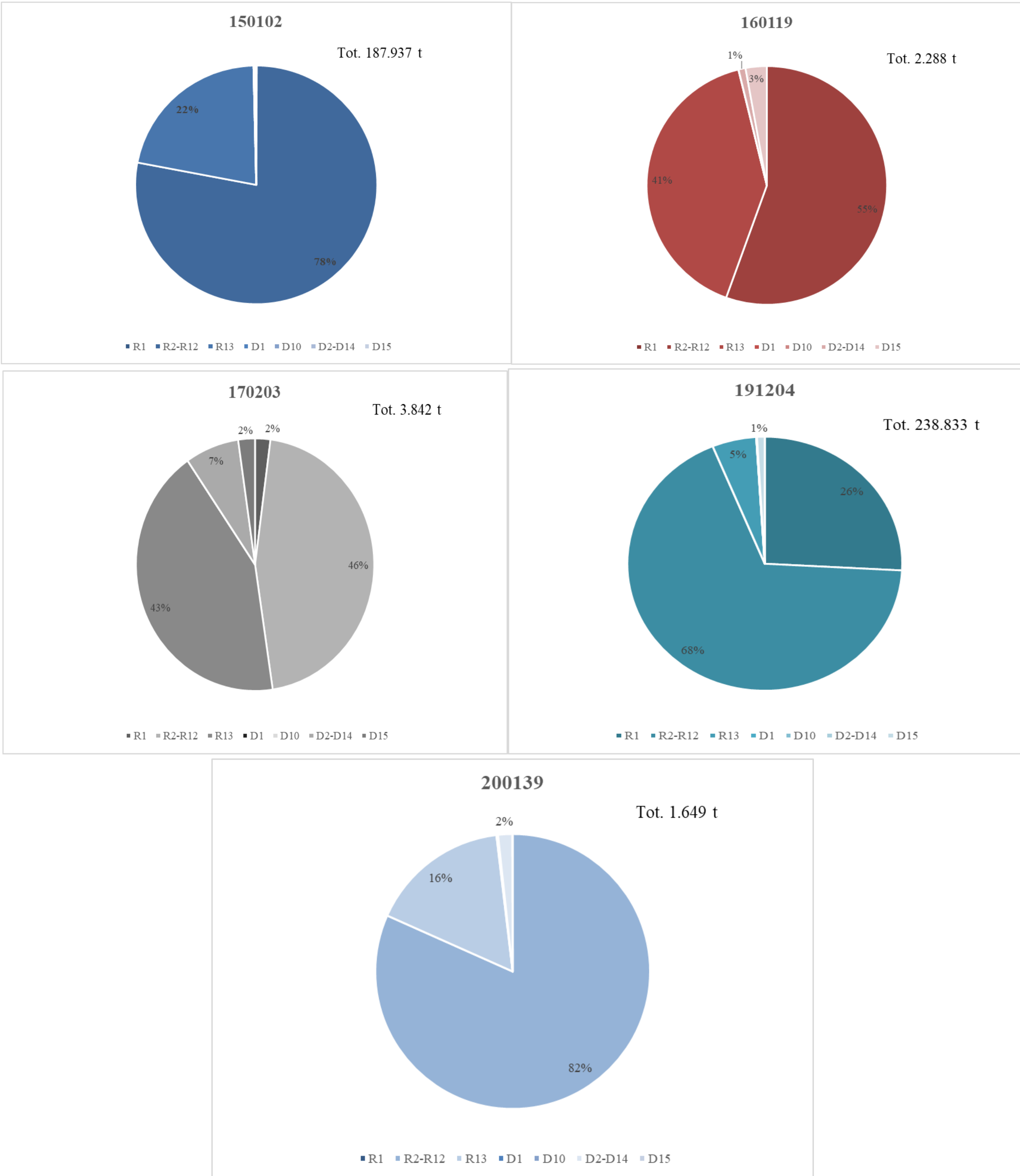


Fig. 88 Recycling and recovery of plastic waste in Emilia Romagna Region, 2017. Analysis by European Waste Code. - Source: MUD database

The overall amount of regional plastics sent to recycling was 62.319t. The recycling rate was about 22%[88]. The relative infrastructure included 115 MRFs where the hugest amount is handled by 9 recycling plants that managed about 90% of PPW separately collected in 2017. No chemical recycling is performed in the region.

In 2017, about 190.436 t of regional plastic waste were exported. The largest amount of plastic waste exported to other regions or countries included waste generated in local waste facilities. It may include waste sorted by polymer and colour (even those are managed by the plants associated to COREPLA).

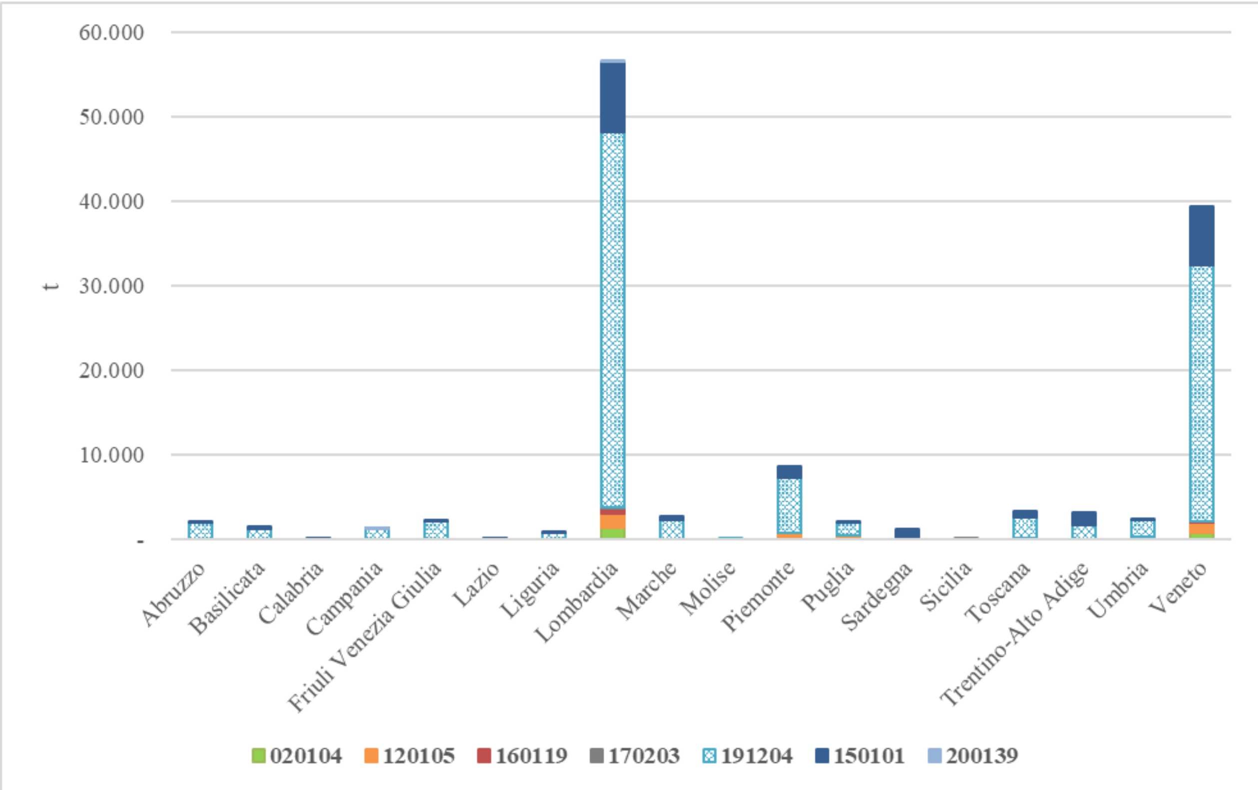


Fig. 89 National export of regional plastic waste, 2017 – Source: MUD database

In 2017, 62.549 t of plastic waste are exported from Emilia-Romagna to foreign countries. MPPW are the main type of plastic waste exported abroad. As shown in the Figure 90, Austria Germany and China are registered as the main destinations.

[88] The recycling rate is calculated in accordance to the method 2 (one of the four calculation methods included in the European Decision 2011/753/UE). It is calculated as the amount of waste sent to recycling overs the total amount of waste collected (in both separated and mixes waste streams)

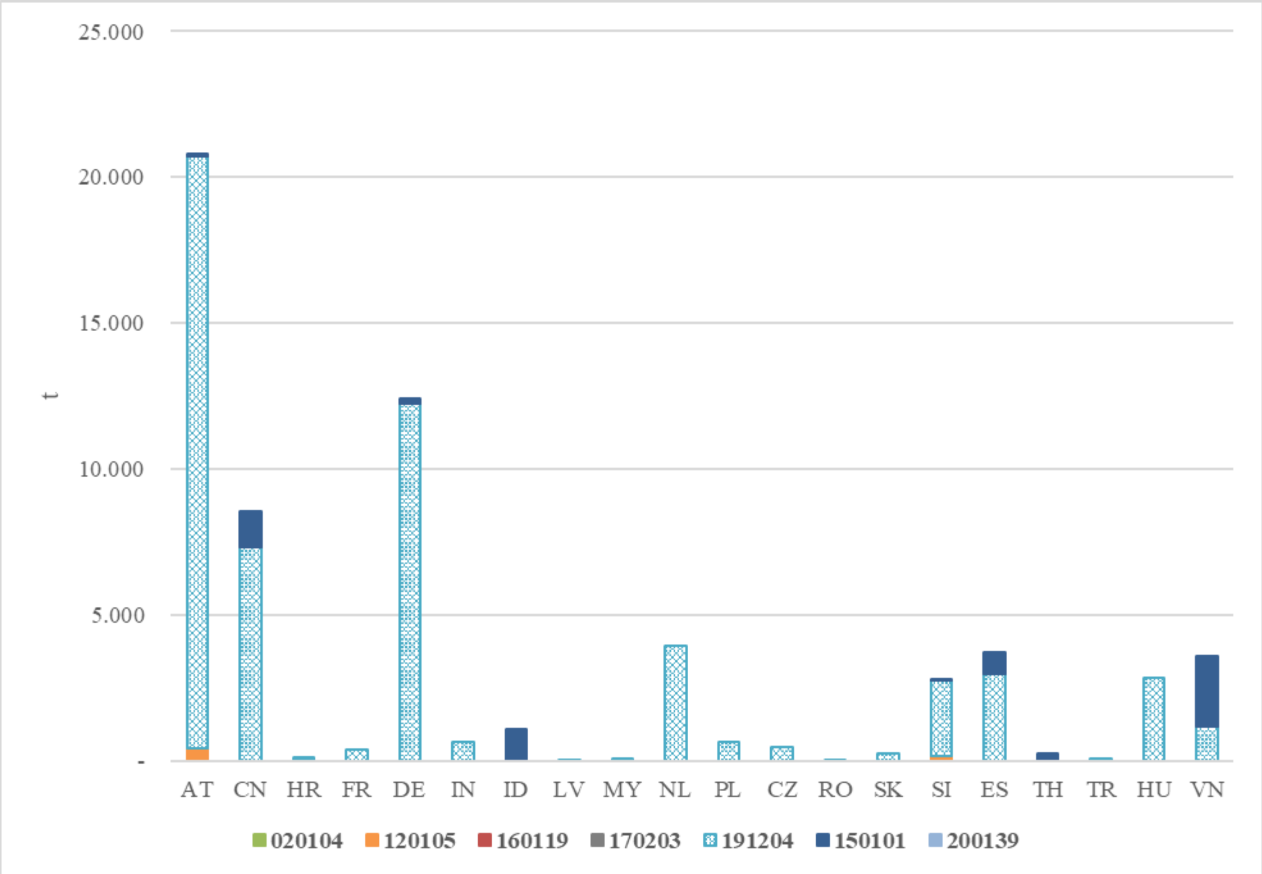


Fig. 90 International export of regional plastic waste, 2017 – Source: MUD database

7.1.4.1 Recycling of municipal plastic packaging waste

Since the municipal plastic waste is the core of this study, the present paragraph investigates the capacity of the regional recycling infrastructure for:

- the overall PPW officially collected in the region through separated collection system (121.044t)
- the fraction of PPW managed by COREPLA that accounted for 96.711t (corresponding to 80% of the overall PPW collected in separated waste collection system)

Currently, the recycling rates are calculated as the ratio between the waste sent to recycling and the plastic waste collected (including the plastic waste collected in the mixed waste bins as well). According to the new definition, the recycling rate is here calculated considering the amount of plastic waste subjected to the R3 treatment. Therefore, scraps generated during the process are excluded. As regards the calculation method, the previous method adopted in Italy was the method n. 2 (ISPRA, 2019). In the Region, the calculation method is more closed to the method n.4 where similar/assimilated wastes are included in the calculation. From the practical point of view, the regional environmental agency calculates the recycling yield summing up the amount of plastic waste sorted by polymers and colours in CSSs (as data given by COREPLA) and the amount of plastic packaging waste (EWC 150102, 200139 and 191204) whom waste treatment is codified by R3 that represent the recycling of organic substances.

Information sources are:
- Regional and provincial environmental protection agencies
- Regional and provincial authorities
- Regional and provincial observatories on waste

through ORSO and MUD databases, yearly report on municipal waste and packaging waste management.

The result has evidenced a recycling yield of 22%, accounting for 62.319t.
From the perspective of the infrastructure, 116 plants contributed to outcome the recycling yield in 2017. In particular, the regional infrastructure has contributed for 70,9% through 28 MRFs. The list is reported below (see Table 32).

Tab. 32 Material recovery facilities handling the regional municipal plastic packaging waste, 2017 – Source: ARPAE, 2018 (in grey=regional plants; __= CSS)

MRFs contributing to the regional recycling rate			
Name	City	Region	Contribution to the recycling rate (%)
ARGECO SPA	Argenta	EMILIA-ROMAGNA	24,3281%
IDEALSERVICE SOC. COOP.	Cadelbosco di Sopra	EMILIA-ROMAGNA	20,8730%
OPPIMITTI ENERGY	Borgo Val di Taro	EMILIA-ROMAGNA	20,0990%
MONTELLO SPA	Montello	LOMBARDIA	9,4304%
MASOTINA SPA	Milano	LOMBARDIA	7,9543%
D.R.V. SRL	Legnago	VENETO	2,4662%
HERAMBIENTE INC RAVENNA CDR	Ravenna	EMILIA-ROMAGNA	1,7527%
IDEALSERVICE SOC. COOP.	Venezia	VENETO	1,2891%
STARPLASTICK SRL	Carcagnano	EMILIA-ROMAGNA	1,2170%
FOREIGN PLANT	-	CHINA	0,7319%
IL SOLCO COOP. SOCIALE SCARL	Savignano Sul Rubicone	EMILIA-ROMAGNA	0,7111%
CAVALLARI SRL	Ostra	MARCHE	0,5349%
SERPLAST SRL	Canzano	ABRUZZO	0,5056%
FOREIGN PLANT	-	SLOVENIA	0,5002%
MASOTINA SPA	Corsico	LOMBARDIA	0,4256%
PLASTIPOL SRL	Silvano d'Orba	PIEMONTE	0,3881%
POLIPLAST SPA	Casnigo	LOMBARDIA	0,3754%
IDEALSERVICE SOC. COOP.	San Giorgio di Nogaro	FRIULI-VENEZIA GIULIA	0,3742%
B&P RECYCLING SRL	San Daniele Po	LOMBARDIA	0,3329%
NUOVA GANDI PLAST SRL	Gandino	LOMBARDIA	0,2888%
PLASTIC-ONE SRL	Mira	VENETO	0,2677%
CONSORZIO CEREA SPA	Cerea	VENETO	0,2663%
AIMAG SPA	Carpi	EMILIA-ROMAGNA	0,2498%
PROJECT FOR BUILDING SPA	Mornico Al Serio	LOMBARDIA	0,2088%
TREGENPLAST S.R.L.	Cassina De'Pecchi	LOMBARDIA	0,1910%
METALFERRO SRL	Castellalto	ABRUZZO	0,1897%
ALIPLAST S.P.A.	Istrana	VENETO	0,1880%
ROSAPLAST SRL	Travedona-Monate	LOMBARDIA	0,1869%

FOREIGN PLANT	-	GERMANY	0,1782%
PANINI	Modena	EMILIA-ROMAGNA	0,1685%
HERAMBIENTE INC MODENA	Modena	EMILIA-ROMAGNA	0,1638%
ECOPOL DI DE CHECCHI WALTER	Porto Mantovano	LOMBARDIA	0,1590%
SOAVE RECUPERI SRL	Soave	VENETO	0,1470%
FOREIGN PLANT	-	AUSTRIA	0,1461%
IMBALL NORD SRL	Vigonovo	VENETO	0,1431%
FOREIGN PLANT	-	CZECK REPUBLIC	0,1386%
MECOPLAST S.R.L.	Cairate	LOMBARDIA	0,1282%
AREA IMPIANTI	Jolanda di Savoia	EMILIA-ROMAGNA	0,1138%
ECOSOL ITALIA SRL	Aviano	FRIULI-VENEZIA GIULIA	0,1050%
FOREIGN PLANT	-	SLOVENIA	0,1003%
EUROPLAST SNC	Montella	CAMPANIA	0,0998%
MIRAPLASTIK	Mirandola	EMILIA-ROMAGNA	0,0994%
NERIPLAST GROUP SRL	Cerreto Guidi	TOSCANA	0,0993%
G.IM.A. SPA	Bedizzole	LOMBARDIA	0,0974%
R.G. POLIETILENE SNC	Salassa	PIEMONTE	0,0751%
FOREIGN PLANT	-	VIETNAM	0,0687%
F.LLI LONGO INDUSTRIALE	Rio Saliceto	EMILIA-ROMAGNA	0,0671%
INTERCOMMERCIO SRL	Vigonza	VENETO	0,0671%
FOREIGN PLANT	-	SPAIN	0,0644%
ASTRO RECYPLAST SRL	Belfiore	VENETO	0,0589%
STARPLASTICK SRL	Parma	EMILIA-ROMAGNA	0,0552%
FOREIGN PLANT	-	NETHERLANDS	0,0540%
DF 3 SRL	Pagani	CAMPANIA	0,0509%
FOREIGN PLANT	Estero	CZECK REPUBLIC	0,0484%
D.R.V. SRL	Legnago	VENETO	0,0480%
GEA SRL	Buscate	LOMBARDIA	0,0477%
MELOREC SAS DI MELONI ALBERTO E C.	Bondeno	EMILIA-ROMAGNA	0,0424%
MANSUTTI RECYCLING DI MANSUTTI JONNI	Spilimbergo	FRIULI-VENEZIA GIULIA	0,0417%
PLASTIC-ONE SRL	Mira	VENETO	0,0414%
ADRIA TERMINAL DOO	Slovenia	SLOVENIA	0,0406%
FOREIGN PLANT	Estero	INDIA	0,0403%
NL RECYCLING ITALIA	Rio Saliceto	EMILIA-ROMAGNA	0,0361%
ALAMAR SRL	Pietralunga	UMBRIA	0,0346%
PLASTISUD S.R.L.	Barletta	PUGLIA	0,0337%
BAODING RUIXIN INDUSTRY AND TRADE CO LTD	-	CHINA	0,0334%
S.C. ALFAPLAST S.A.	Romania	ROMANIA	0,0329%
SIRE	Bressana Bottarone	LOMBARDIA	0,0323%
ENERGIE AG SUDTIROL UMWELT SERVICE S.R.L.	Egna	TRENTINO-ALTO ADIGE	0,0299%
FOREIGN PLANT	-	AUSTRIA	0,0293%
MATERIE PLASTICHE PRATESI S.R.L.	Prato	TOSCANA	0,0284%
GRANULPLASTIC S.R.L	Modugno	PUGLIA	0,0256%
ECOPLAST S.A.S DI FAVOTTO BENVENUTO	Sandrigo	VENETO	0,0236%

POLIPLAST SPA	Casnigo	LOMBARDIA	0,0209%
PLASTIC LEFFE MOSCONI S.R.L.	Leffe	LOMBARDIA	0,0199%
ITALCAVE SPA	Taranto	PUGLIA	0,0198%
MELAMPO DI DAMATO VITO RUGGIERO	Barletta	PUGLIA	0,0188%
MONTELLO SPA	Montello	LOMBARDIA	0,0173%
RDB PLASTICS D.O.O.	-	SLOVENIA	0,0173%
OPPIMITTI ENERGY	Bedonia	EMILIA-ROMAGNA	0,0170%
RIGENERA SRL	Terni	UMBRIA	0,0151%
FOREIGN PLANT	-	CROATIA	0,0146%
HERAMBIENTE INC CORIANO	Coriano	EMILIA-ROMAGNA	0,0144%
FEA - FRULLO ENERGIA AMBIENTE	Granarolo Dell'Emilia	EMILIA-ROMAGNA	0,0120%
FOREIGN PLANT	-	MALAYSIA	0,0117%
HD POSITIVO SRL	Osimo	MARCHE	0,0102%
EURO-CART SRL - CORNEDO VICENTINO	Cornedo Vicentino	VENETO	0,0099%
SEORAN SRL	Acquanegra Cremonese	LOMBARDIA	0,0091%
ORSATO DI ERIC ORSATO & C. SNC	Viano	EMILIA-ROMAGNA	0,0089%
ACF ANDREIS SRL	Gussago	LOMBARDIA	0,0089%
ADIGE AMBIENTE PLASTICHE SRL	Bedizzole	LOMBARDIA	0,0073%
FOREIGN PLANT	-	HONG KONG	0,0069%
MAC PLAST DI MENICONI EMILIANO	Pietralunga	UMBRIA	0,0067%
ADIGE AMBIENTE PLASTICHE SRL	Bedizzole	LOMBARDIA	0,0065%
FORPLAST SRL	Castell'Arquato	EMILIA-ROMAGNA	0,0060%
REPLASTICS SRL	Prevalle	LOMBARDIA	0,0049%
FOREIGN PLANT	-	GERMANY	0,0049%
IMBALL NORD SRL	Vigonovo	VENETO	0,0048%
AMICI DI REGGIO CHILDREN	Reggio Emilia	EMILIA-ROMAGNA	0,0046%
HERAMBIENTE INC RAVENNA CDR	Ravenna	EMILIA-ROMAGNA	0,0043%
VALSIR SPA	Vobarno	LOMBARDIA	0,0043%
ECO PLAST SRL	Modena	EMILIA-ROMAGNA	0,0038%
FOREIGN PLANT	-	TURKEY	0,0037%
FOREIGN PLANT	-	MALAYSIA	0,0037%
ISACCO S.R.L.	Gabbioneta Binanuova	LOMBARDIA	0,0031%
CERPLAST S.R.L.	Formigine	EMILIA-ROMAGNA	0,0026%
ECOREP SRL	Castello d'Argile	EMILIA-ROMAGNA	0,0026%
FOREIGN PLANT	-	BELGIUM	0,0017%
ECORICICLI SRL	Odolo	LOMBARDIA	0,0016%
MELOREC SAS DI MELONI ALBERTO E C.	Bondeno	EMILIA-ROMAGNA	0,0009%
GRANULPLASTIC S.R.L	Modugno	PUGLIA	0,0008%
FOREIGN PLANT	-	BULGHERIA	0,0006%
FOREIGN PLANT	-	CROATIA	0,0005%
FOREIGN PLANT	-	NETHERLANDS	0,0004%
FOREIGN PLANT	-	HUNGARY	0,0004%
ROSAPLAST SRL	Travedona-Monate	LOMBARDIA	0,0002%
IL SOLCO COOP. SOCIALE SCARL	Savignano Sul Rubicone	EMILIA-ROMAGNA	0,0001%

The recycling chain is strongly fragmentated. Many efforts have been done to re-build the MFA of the waste handled by COREPLA.

The following scheme (Figure 91) shows the layout of the recycling chain including all the plants working in the pre-sorting, sorting and recycling of the MPPW generated in ERR and managed by the National Consortium. Regarding the CSSs, the amount of waste imported, exported or stocked contributes to the final outputs. The specific regional amount is also outlined.

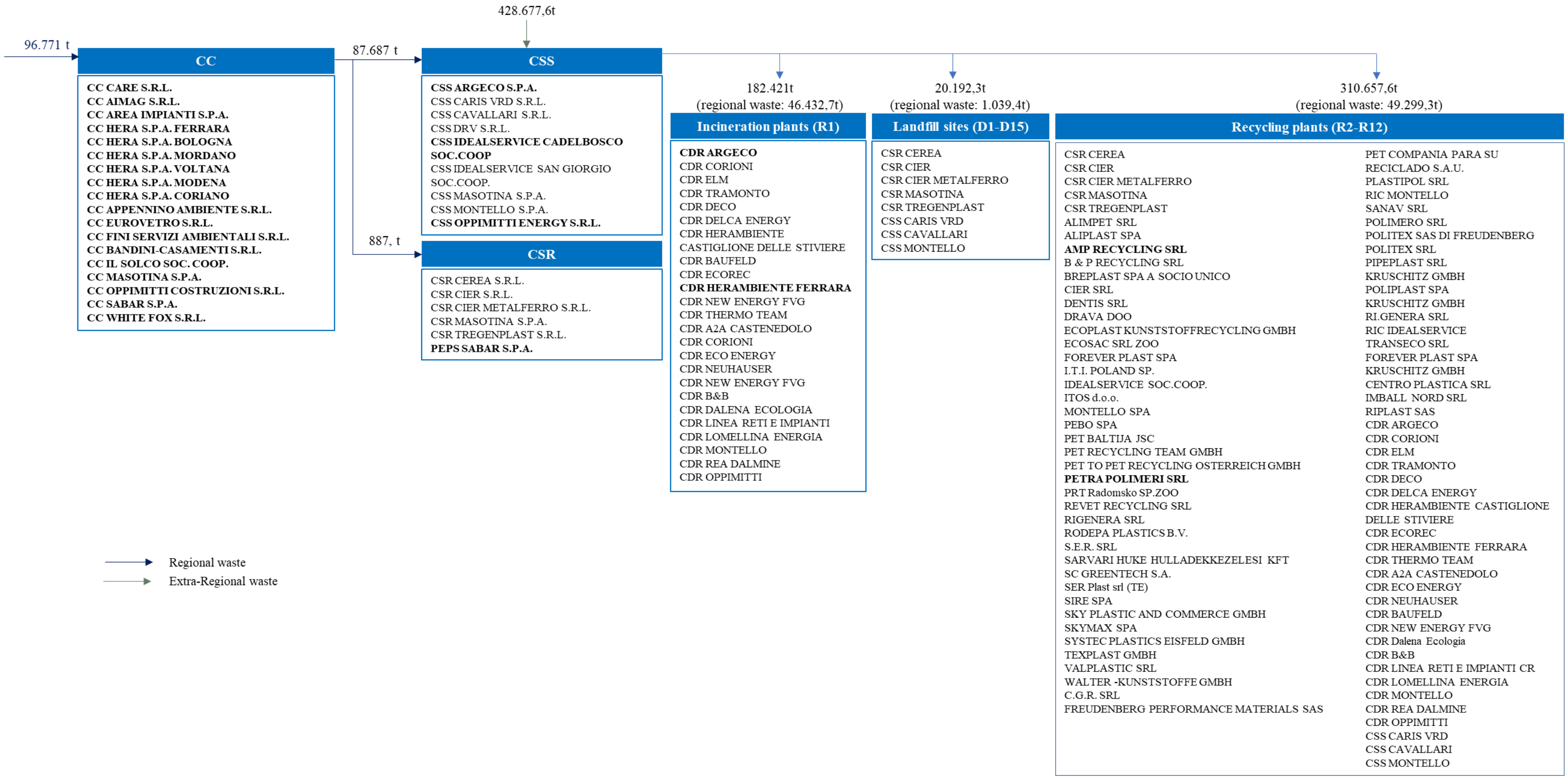


Fig. 91 Management of municipal plastic packaging waste in the COREPLA syste

The final step (representing the contribution of the National Consortium to the recycling) is underlined by the activities performed by the CSSs that select the plastic waste by polymers and colours. As aforementioned, about 49.299,3t of plastic wastes are sorted by 15 plants (as part of COREPLA). In particular, 5 are CSRs, 9 are CSSs and one is a platform working on the valorization of PS packaging. The output will be sent to EU recyclers. Only two of them are located in the region.

The following graphs, maps and tables shows the national as well as European market of the plastic waste sorted by the CSSs listed above.

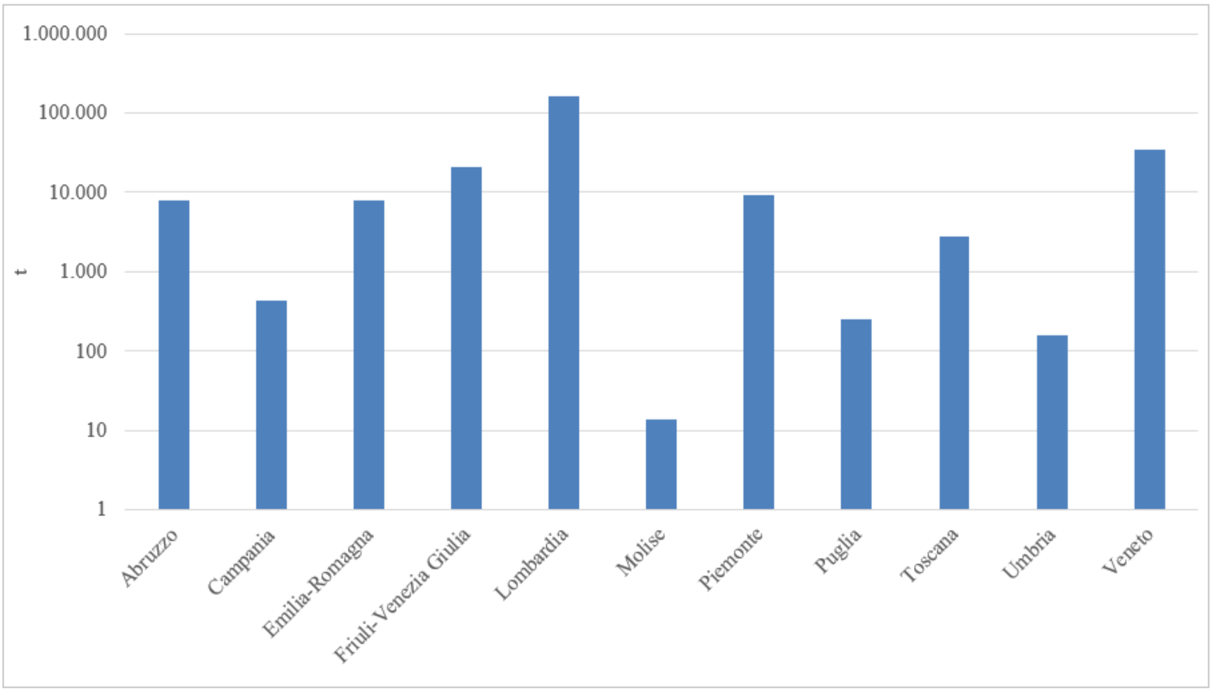


Fig. 92 National market of plastics sorted out by CSS, 2017 - Source: MUD database

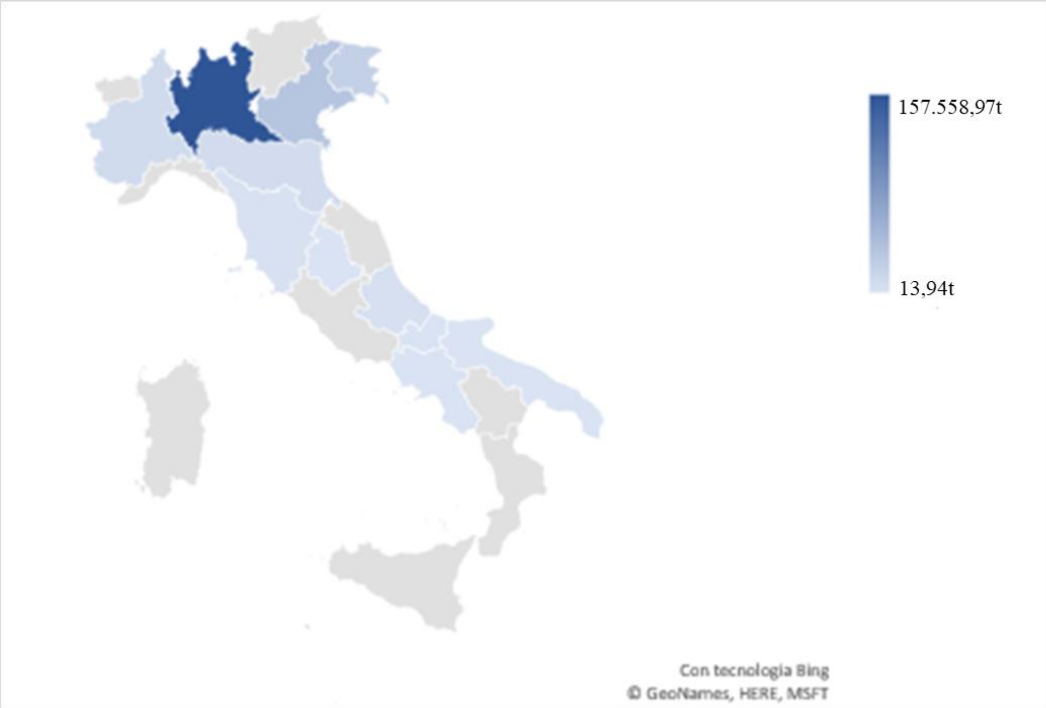


Fig. 93 Italian market of sorted plastics out by CSS, 2017. Analysis by quantity and region - Source: MUD database

Tab. 33 List of the main Italian recycling plants receiving waste from COREPLA - Source: MUD database. NS= Not specified

RECYCLING PLANTS	PROV	AMOUNT (ton)	OUTPUT
MONTELLO S.P.A.	BG	110.176	PET, HDPE, LDPE, PP, PE
IDEALSERVICE SOC.COOP.	RO	20.552	Plasmix PO
SKYMAX S.P.A.	TV	17.038	NS
POLITEX SAS DI FREUDENBERG POLITEX S.R.L.	CO	15.262	NS
VALPLASTIC S.R.L.	PD	8.412	rPET

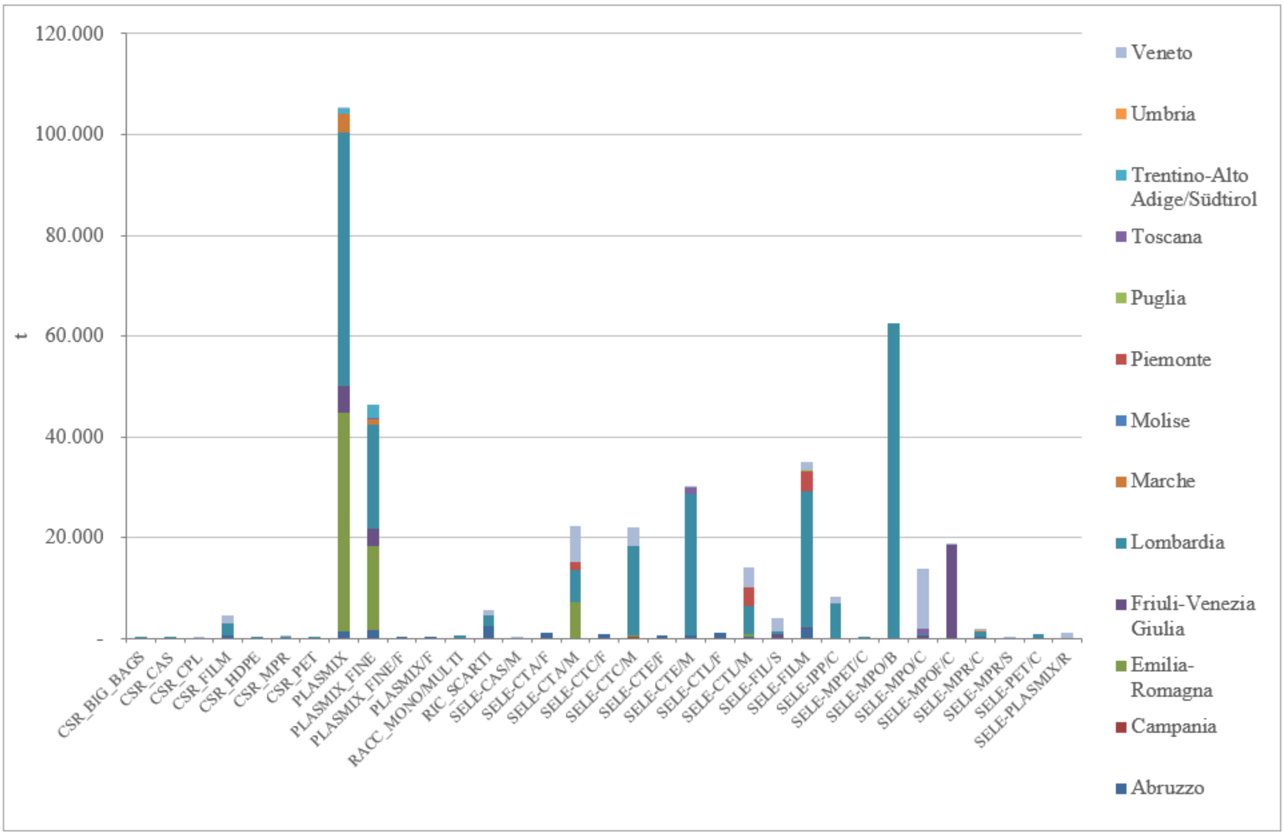


Fig. 94 Italian market of sorted plastics out by CSS, 2017. Analysis by quantity, product and region - Source: COREPLA database

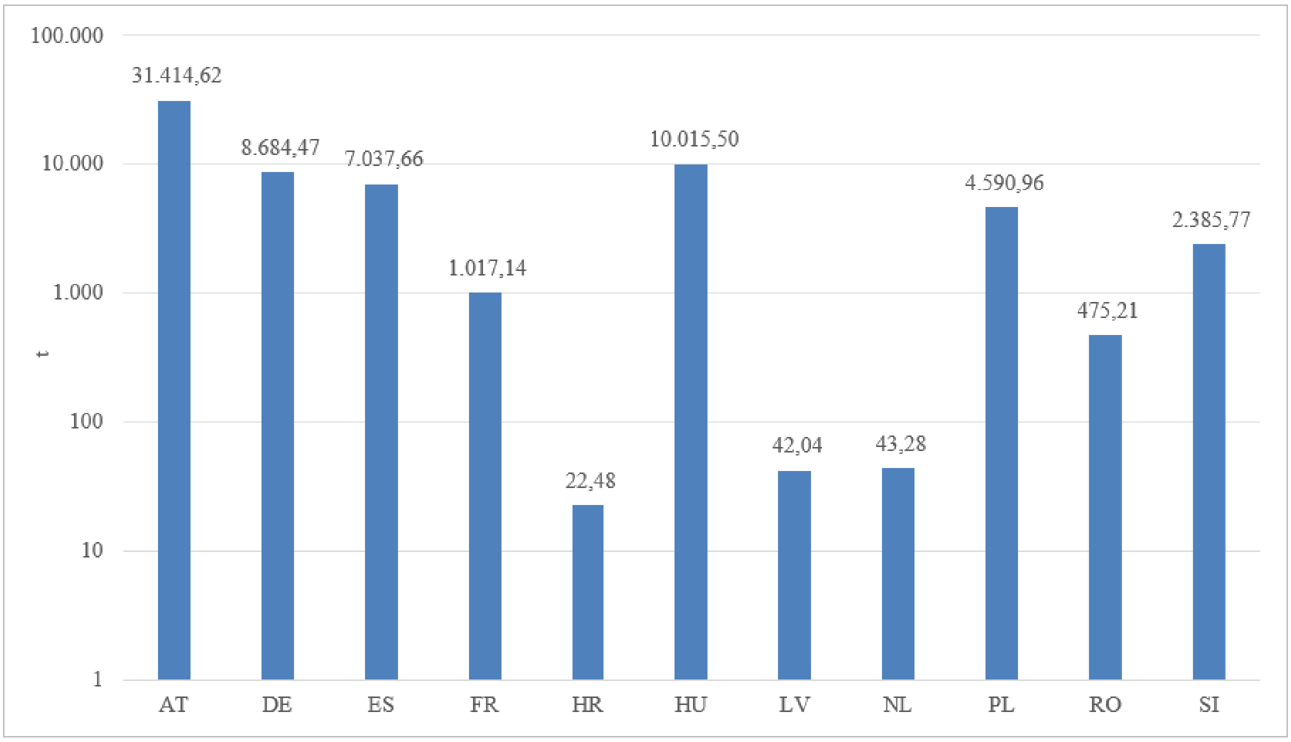


Fig. 95 European market of plastics sorted out by CSS, 2017. Analysis by country - Source: MUD database

Fig. 96 European market of sorted plastics out by CSS, 2017. Analysis by quantity and country - Source: MUD database

Tab. 34 List of the main European recycling plants receiving waste from COREPLA - Source: MUD database. NS= Not specified

RECYCLING PLANTS	COUNTRY	AMOUNT (ton)	OUTPUT
SARVARI HUKE HULLADEKKEZELESI KFT	Hungary	10.016	rPET
TEXPLAST GMBH	Austria	8.481	rPET
SKY PLASTIC AND COMMERCE GMBH	Austria	8.411	NS
ECOPLAST KUNSTSTOFFRECYCLING GMBH	Austria	7.671	rPET
PET RECYCLING TEAM GMBH	Austria	7.230	rPET

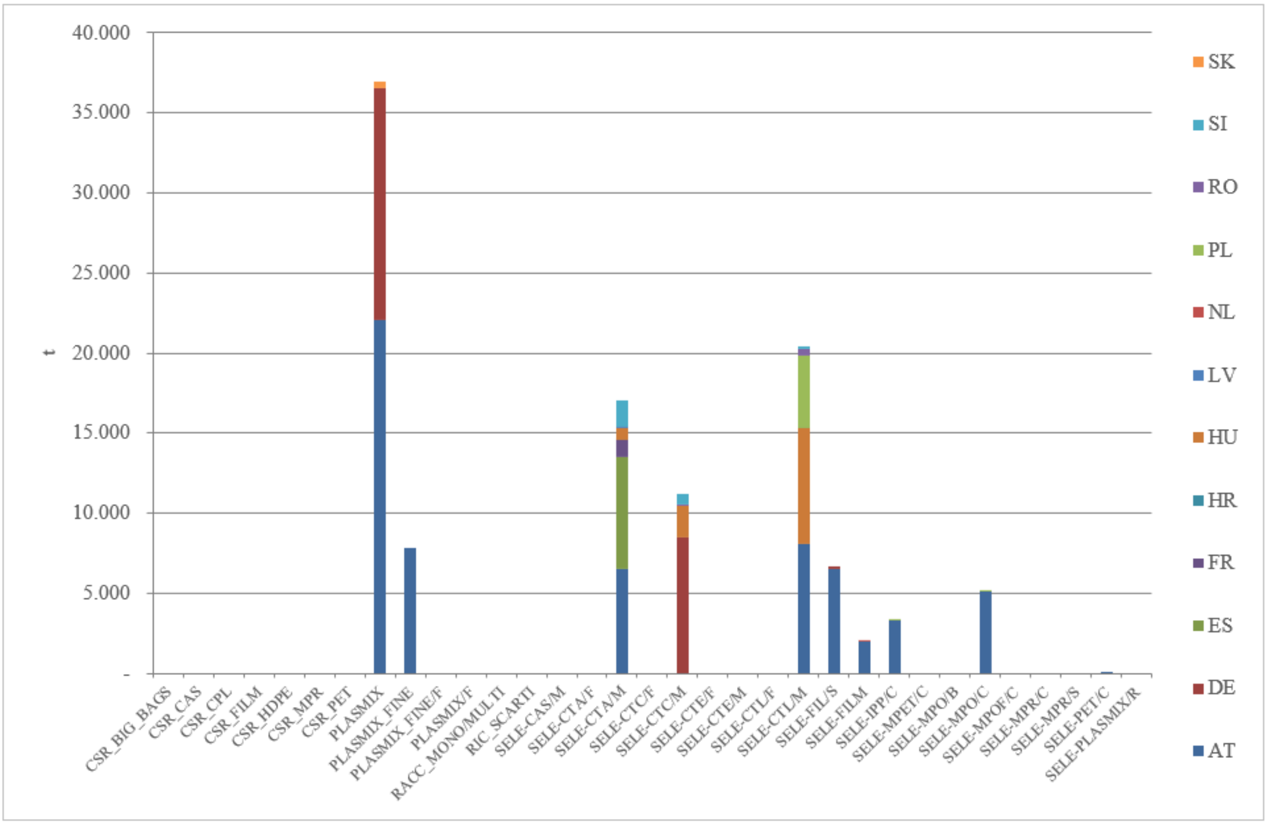


Fig. 97 European market of sorted plastics out by CSS, 2017. Analysis by quantity, product and region - Source: COREPLA database

As reported in the Table 32, the remaining amount (13.019,7t) is managed by 101 plants. It follows that the recycling chain is strongly fragmentated and difficult to monitor.

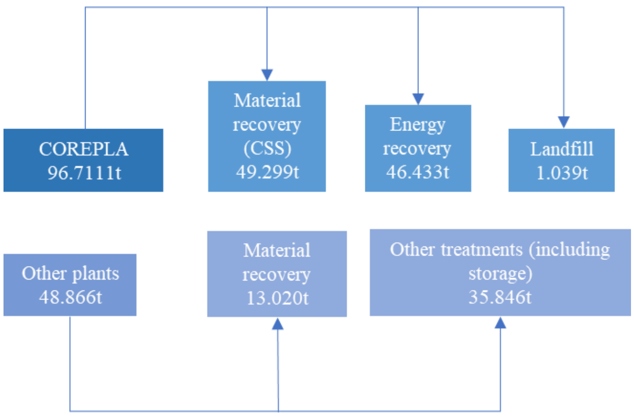


Fig. 98 Recycling chain, End of Life performance

The MFA has evidenced that a high amount of MPPW are incinerated or landfilled. No information are available on the type of products and their destination.

The lack of data on the real recycling in one side and the low recycling performance in another, highlight the necessity to monitor the real recycling yield to be intended as the amount of waste effectively turned up in SPs. The estimation of the current amount of SPs will support a robust strategy to push the market of SPs and therefore the demand. In order to do that, a better eco-design (validated by the local waste infrastructure) may help to reduce the generation of plasmix and similar unintended outputs. It follows that the strategy is more than necessary: the reduction of waste at first, the increase in the quality of collection then and the problem of the plasmix should be fixed.

These key-points have stimulated:

- the need to know the regional market of SPs and therefore, the perspective of converters (as summarized in the paragraph 7.2)
- the necessity to realize a barriers analysis (reported in the paragraph 7.3) in order to understand the gaps taking place along the value chain

7.2 Circular economy in regional plastic packaging system

As illustrated in the chapter 4, the CE practices improving the plastic packaging sustainability can be summarized as:

- **Servitization**
- **Eco-design (DesignforX)**
- **Lightweighting**
- **Material substitution**
- **Valorization of by-products and waste**

According to Le Blevennec et al. (2019), five main ecodesign principles influence the various stages of the lifecycle of plastic:

- **Design for sustainable sourcing**
- **Design for optimised resource use**
- **Design for environmentally sound and safe product use**
- **Design for prolonged product use**
- **Design for recycling.**

In this work, eco-design for and from recycling are contemplated. In order to understand the starting point of the work, all possible aspects regarding the design requirements, the current use of SPs, the recycling performance are investigated. The investigation is performed at different level with different tools and instruments as part of the participative methodology.

The following paragraphs summarizes the results of surveys, interviews, questionnaires and opinions of the actors working in the system.

7.2.1 Circular economy in conversion process

The increasing environmental awareness, the return of image, the MBIs implementation and the legislative pressure are only some of the factors contributing to the growing demand of recycled plastics to include in new products. The fact is particularly acute among the big corporations that are committed to voluntary pledges to reduce the use of virgin-plastics substituting it with non-virgin ones. It is emphasized among packaging manufacturers, especially those produce bottles. Since the FCM requires high-quality SPs, the boost towards upcycling is the main concern of the recyclers who want to make profitable their business despite the variety of barriers hindering the market.

a. Activity A – part I: examination of recycles uptake

Regarding the usage of the SPs, a deep examination was performed in 2012 and 2018 in order to compare the business models of regional companies before and after the diffusion of the EU commitment on plastics in one side and draw some considerations about the market of SPs in another.

The study was undertaken by Alma Mater Studiorum, University of Bologna (UNIBO) and supported by the Consortium for innovation and technology transfer of Emilia-Romagna region (ERVET). The results here illustrated are summarized within the scientific paper published by Paletta et al. in 2019 (2019). The exploration has involved 364 companies. The study consisted of surveys, administrated in two different tranches, in the years 2012 and 2018. Of the 364 companies categorized by the C22.22 NACE code, 41 (12%) took part in the study performed in 2012. This sample has been used to replicate the investigation in the year 2018. The second survey has been submitted to the same companies that had fulfilled the survey in 2012. Owing to modifications on business segments of few companies, the final number of conversion companies under the comparative investigation has been amounted to 35.

According to product-specific requirements, the investigated companies manufacture plastic products through injection, extrusion, blow moulding, welding and printing of different polymers. Respondents use general polymers (especially PP, PE, PS, PVC), engineering polymers (such as Nylon, PA, PET etc.) and elastomers. The use of thermoset polymers (PUR, Urea, Silicon etc.) and specialty engineering resins, is rather low; bio-based polymers are only experimented in some processes. The market primarily served by these companies are packaging, automotive, B&C and, less considerably, EEE and medical.

Data on the use of non-virgin plastics, reveal a situation not so changed during the last six years (2018 in comparison with 2012). The number of companies that use non-virgin plastics remains almost the same in 2012 and 2018. Trend inversion has been registered for two companies.

The investigation reveals that most of pro-active companies (referring to companies that use non-virgin plastics) has a consolidated experience in valorising plastic debris, reinserting them in the same manufacturing process after a milling process. The additional use of non-virgin plastics is testified in few companies.

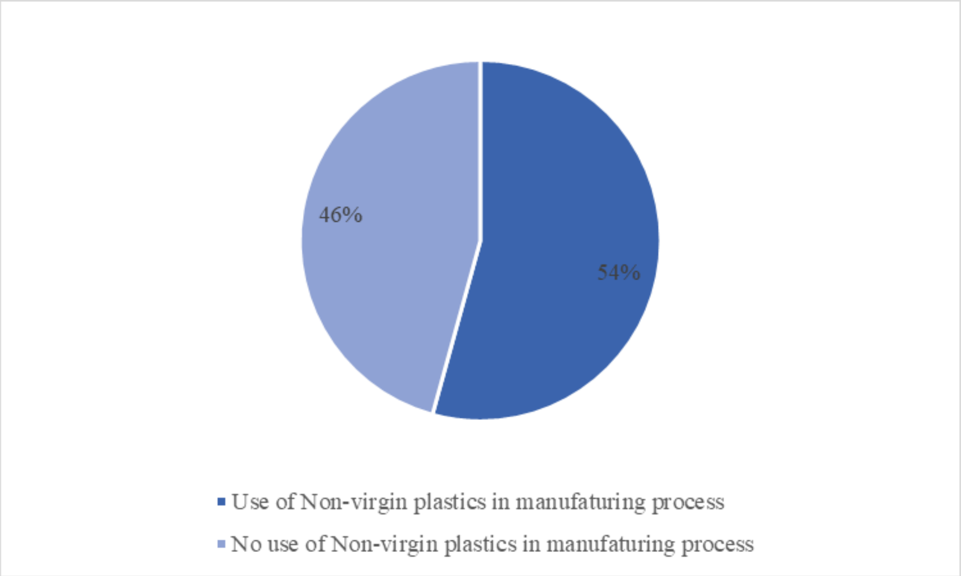


Fig. 99 Use of virgin and non-virgin plastic materials in plastic industry (C22 NACE code) in Emilia Romagna region, 2018 – Source: Paletta et al., 2019

The preference for pre-industrial and industrial debris over secondary plastics is mainly due to:

- Easy collection because of the few points of generation
- More predictable composition
- Clear composition of a single type of polymer
- Lower content of impurities
- Greater compatibility with the following manufacturing processes
- Lower price
- Easy availability in the regional market

Even if the number of pro-active and un-reactive companies remains almost the same, the amount of recycled plastics is generally increased in the proactive companies, especially in those having the highest use of alternative plastics, reaching over 50% of green supply (Figure 100).

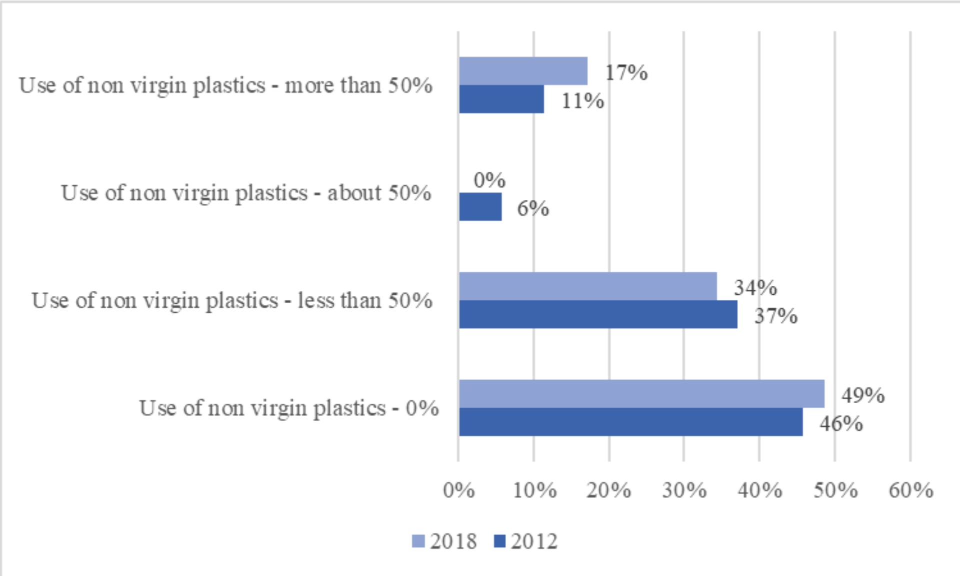


Fig. 100 Percentage of non-virgin plastic use in plastic industry (C22 NACE code) in Emilia Romagna region, 2012-2018 – Source: Paletta et al., 2019

It follows that while pro-active companies have picked up the positive impact of rethinking supply towards more sustainable resources provision, the perception about plastic problem remains not so warned among all plastic converters. This study has also examined the framework of barriers limiting the transition towards a more sustainable supply chain. A deeper explanation is included in the paragraph 7.3.

7.2.2 Circular plastic economy in recycling activities

The status of SPs, that are no longer waste, doesn't allow the traceability by official data collection scheme: when wastes are transformed in secondary resources, the legislation doesn't require information about the amount, the type, the quality and the further applications. In addition, when the wastes enter the waste treatment plant, it loses information about its origin thus limiting the analysis for separated plastic packaging types. The initiative here underpinned aims to fill this gap on material stream.

b. Activity B - part I: plastic waste valorization by material composition

The activity B aims to explore the performance of recycling infrastructure in ERR. A questionnaire was sent via email to the plants authorized for recycling and recovery processes (classified by R3, R4, R5 and R12 waste treatment codes) in 2017. The survey has included 91 plastic waste managers: 59% dealing with R12, about one third performing recovery by R3, R4, R5 waste treatment codes, while the remaining plants (8%) are authorized for all waste processes. The respondents accounts for 19,5% of the total recovery and recycling plants located in the region. However, most of them manages the largest amount of plastic waste in ERR. 9 respondent plants are coordinated by COREPLA as pre-sorting plants, while 2 plants handle industrial plastic packaging, as part of PIA platform. As for Independent Consortia, 3 respondent plants are members of CONIP. The results are described in the scientific paper in the process of being published by Foschi et al. (2020).

The outcomes deal with the province of plastic waste, the input-output flows and the destination of the products.

As illustrated in the graph below (Figure 101), the main amount of incoming waste stream refers to municipal wastes that arrive from the region itself, Lombardia and Campania.

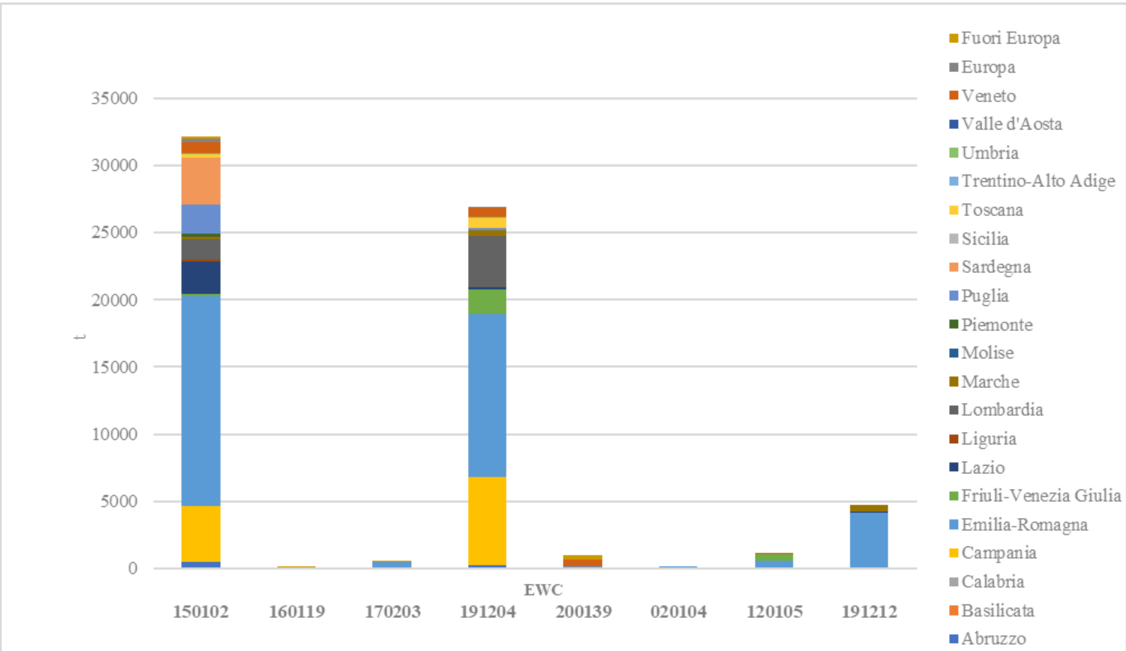


Fig. 101 Import of plastic waste (including plastic packaging waste), 2017. Analysis for the regional waste plants (part of local investigation)

Most of the output (62%) consists of plastics sorted by polymer and colour, as this operation is carried out by 9 respondent plants, while the remaining 38% refers to SPs re-manufactured through a complete recycling process as activity performed by 6 plants. Just one plant manages both the outputs (sorted polymers and SPs) and 3 companies did not specify either. Output quantities are specified in Table 35.

Tab. 35 Outputs of regional waste plants (results of local investigation), 2017

Plastic waste, by polymer		SPs	
Type of Polymer	**Amount (t)**	**Polymer**	**Amount (t)**
ABS	16	**ABS**	3
HDPE	846	**HDPE**	16,049
LDPE	11,831	**LDPE**	855
LLDPE	0	**LLDPE**	247
PET	1,208	**PET**	11,846
PP	2,905	**PP**	3,217
PS	119	**PS**	10
PVC	104	**PVC**	101
COREPLA mix	28,648	**Other**	269
Free market mix	5,748		
Plasmix	929		
Other	871		

Since most plants are sorting plants associated to COREPLA, a huge amount of plastics (55,34% of the output) has been sold by COREPLA through electric auctions.

Regarding the main destination, the primary market is covered by Emilia Romagna, Lombardia, Veneto and other regions in Europe and generally in the world. Concerning the polymeric composition, PET and PE are the most demanded polymers.

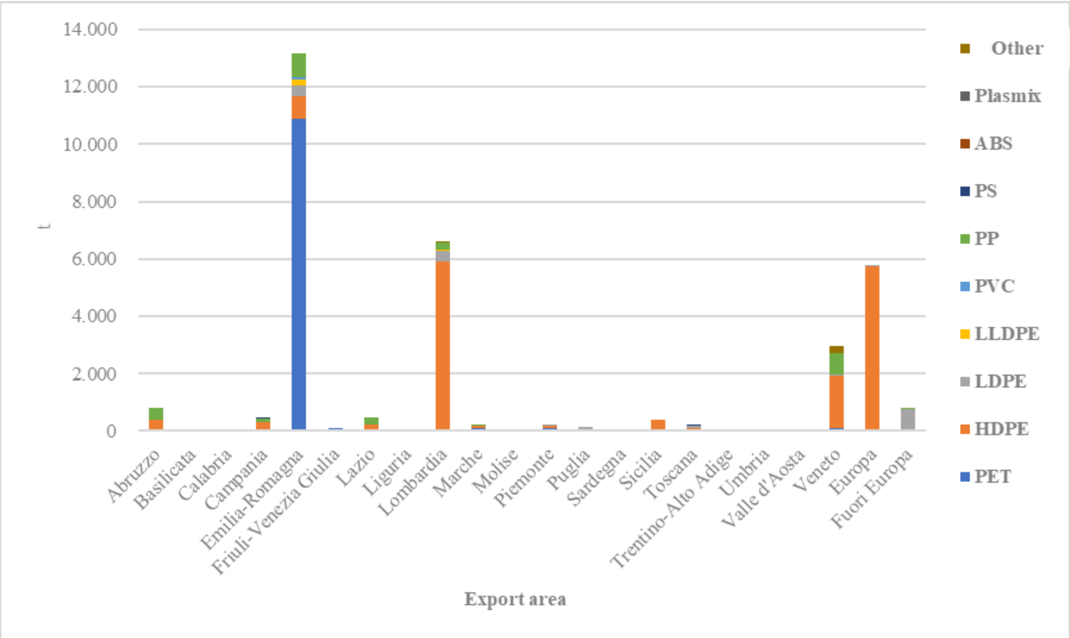


Fig. 102 Export of plastic waste (including plastic packaging waste), 2017. Analysis for the regional waste plants (part of local investigation)

7.3 Barriers analysis

7.3.1 Multi-criteria and multilevel perspective and analysis

The barriers analysis aims to identify the bottlenecks limiting the implementation of recyclability and recycling activities in the region. The analysis is carried out by using the **MLP**. The MLP is an analytical approach to describe processes of innovation and transitions in socio-technical systems. It can be used to better understand the relevant context of system innovation projects (De Vincente et al., 2016).

The three level of investigation are here listed and explained:

- **Macro level** is the wider context embracing all the LT trends and crises (E.g. industrialisation, urbanisation, demography, macro-economy, climate change, geopolitics, raw material stocks etc.)
- **Meso-level** is contextualized into the topic of interest, referring to the way the stakeholders use resources, technology and knowledge and shape the current system in which they are embedded (E.g. rules and regulation, infrastructure, economic structures, technological lock-ins, behaviour etc.)
- **Micro-level** is the point of view of single stakeholder or group of stakeholders and their opinions and perceptions towards the field of interest

According to the three levels, the barriers analysis involves:

- **the system** (and in particular the stakeholders' dimension) as micro-level
- **the environment 1** (and in particular the value chain) as meso-level
- **the environment 2** (that includes the wider connection between the system, the value chain and the wider eco-system) as macro-level

Since many factors may affect the study, four criteria (political-legislative, economic, social and technical-technological) have been identified. These criteria have supported the PESTEL analysis depiction.

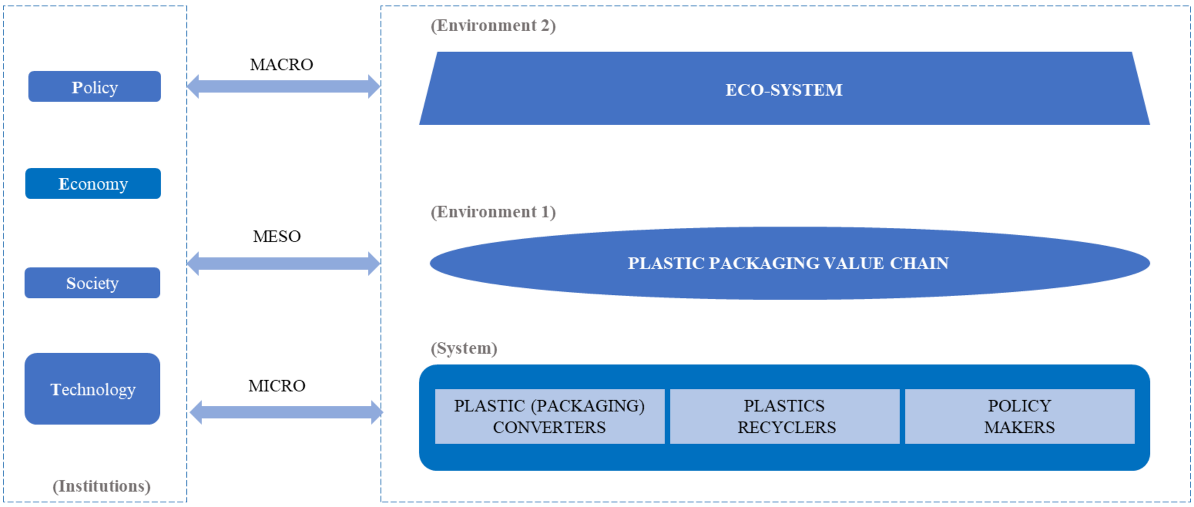


Fig. 103 Multi-level perspective (Micro, meso and macro) and PESTEL (Political, Economic, Social and Technological) barriers analysis

7.3.1.1 Micro-level analysis: plastics converters viewpoint

Since the micro-level analysis involves the actors working in the regional system, the study has been done though an "internal examination" by reporting the opinions of converters firstly and recyclers then. These activities have been figured out within the engagement process in terms of surveys.

c. Activity A – part II: results of the stakeholder consultation

The activity A (regarding the assessment of recycled plastics usage among regional converters) was also composed by a second part aimed to investigate the main challenges affecting the recycles usage.
The bottlenecks figured out through the investigation have been linked to the existing literature in order to verify the truthfulness. Common consensus has been found. Therefore, being validated by the literature review, the following barriers have been officially considered in the backcasting process.

From the political point of view, the current regulatory framework does not yet adequately support the use of SPs. The respondents have usually referred to the following policies:

- REACH Regulation that sets out criteria for classifying a substance as a "substance of very high concern" (SVHC) (European Parliament and of the Council, 2006).
- RoHS Directive that regulates the presence of Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls (PBB) and Polybrominated diphenyl ethers (PBDE) in products (European Parliament and of the Council, 2017)

From an economic point of view, the uncompetitive prices of recycles (that reflect the fluctuation of oil price first and the waste management cost secondly) restricts the demand for sustainable materials. In addition, limited availability for specific polymers and lack of constant volume emphasize the problem. The stakeholders voiced the needs of having more economic and financial support to overcome these difficulties.
Social barriers are taken into consideration because of customers' disinterest towards sustainable purchase. The hostility in the direction of innovative materials and products in some cases and the inert attitude towards news business model in other cases have been perceived during the interviews. The sceptical behaviour of manufacturers towards resources coming from waste is also highlighted by Polymer Comply Europe (2018).

Technical and technological barriers can affect both products and processes. The main barriers highlighted by the respondents concerned with the quality issues of the recycled materials. As indeed Lange and Wyser (2003) emphasized, the insufficient quality of recycled polymers exacerbates the problem regarding the presence of non-recyclable and non-target materials in current plastic-based products. In particular, the presence of some impurities can cause some problems in relation with the correct process temperature, thus affecting strength and durability, colour and other esthetical implications and causing also a fall in mechanical performance (Pivnenko et al., 2016). These barriers are also pointed out by the EU converters as part of the investigation carried on by the EU Plastics Converters Association and Polymer Comply Europe in 2018 (2018)[89]. Summarizing, the main barriers are closely linked to the poor quality, the low availability the uncompetitive price of SPs and finally the presence of regulatory requirements hampering the use of SPs in new product manufacturing.

As it is well-known that recycled plastics have a positive impact on the environment, no barriers have been identified. However, the interviewers are conscious that this practice must be supported by a life cycle approach and therefore, eco-design.

Although legal barriers may overlap with the legislative ones, this section aims to identify bottlenecks in the field of health, safety, and the like. Considering that waste may contain chemicals that are now considered hazardous, if products are not labelled, or information on chemical content is not traceable, a clear potential risk can exist. Sometimes, converters hold to make some analysis to verify the chemical composition of

[89] It refers to the *2nd European survey on the use of recycled plastics materials in Europe's plastics converting industry*. The survey has seen the participation of 376 companies from 21 different countries.

recycled plastics. The governmental bodies has worked on regulating the presence of hazardous wastes, especially in transboundary movements (UN Basel Convention, UN Rotterdam Convention), the presence of persistent organic pollutants (UN Rotterdam Convention) and the restriction of certain hazardous substances (RoHS I, II, Reach Regulation).

7.3.1.2 Micro-level analysis: recyclers viewpoint

d. Activity B – part II: results of stakeholder consultation

Even in this case, the quantitative analysis has been enriched by a qualitative one through semi-structured interviews. The outputs are deeply investigated and verified according to the existing literature. In some cases, site-visits and inspections have been performed to have a better understanding of the technical and technological challenges.

According to the political landscape, the higher pressure gained by the recyclers regards the blocking time of authorization for the Waste criteria. Other critical issues regard the scrap's management because of the lack of a clear legislation on by-products. In fact, recyclers valorize by-products (through external circuit) as less as possible because of the possibility to come across the illegal waste management area that is prosecuted as a crime. Considerable relevance has been given to the application of REACH that binds the recyclers to make chemical analysis to identify the composition of waste.
Regarding the economic barriers, the interviewers have pointed out the absence of a constant volume of plastic waste and, at the same time, the difficulty to manage irregular and significant peaks of waste that cause additional costs and market vulnerability. The Chinese import ban has widely and negatively affected the regional waste infrastructure. It has congested the warehouse of the facilities because on the other side, the price for incineration has increased. The unsustainability of the waste management system (WMS) has favoured illegal fires and trades[90].

From the social point of view, no barriers have been underlined by recyclers.

From the technological point of view, the miscommunication between packaging designers and recyclers has led to create many problems to the recycling process. The introduction of a functional barrier in packaging applications has led the materials being rejected for recycling. Other critical issues affecting the recycling refers to those packaging that cannot be detected by NIR technologies. An example is given by bottles characterized by sleeves covering all the man body of the products; the difficulty to scan the material characterizing the main body of the bottle makes the item rejected for recycling. In addition, the presence of some impurities and their removal process add costs and reduce the competitiveness of recycled plastics (Villanueva and Eder, 2014). Contaminations is manifested when recyclable plastics are mixed with non-recyclable materials, or non-targeted materials or with liquid, oils and other residues (E.g. food residues) (Hahladakis et al., 2018). While some contaminants are removed through cleaning process, other (especially those present in personal care products) have high boiling points and low volatility, making them difficult to remove (Hopewell et al., 2009). IT is also possible that contaminants damage mechanical sorting equipment (Hahladakis et al., 2018). Recyclers have also manifested concerns about the presence of chemicals. Since the REACH Regulation doesn't allow to inform waste operators on the presence of chemical substances, analysis have been done in order to ensure the respect of the limits imposed by the CLP Regulation. Moreover Crippa et al. (2018) write that the uncertain chemical composition of recycled plastics hampers the potential applications even for a first additional reprocessing cycle. It creates an additional problem: the

[90] This discussion is scrutinized in the legal barrier analysis.

increasing consumption of chemical substances with significant uncertainties on hazard properties and on unintentional releases, has also created pressure on health protection to such a point that policy has reacted by hindering the use of recycled polymers in specific applications[91]. These obstacles to recycling can be generally summarized as the effect of the lack of harmonization between chemicals, wastes and products legislation. And again, although the main plastics production is dominated by thermoplastics, thermoset plastic applications are significant (especially PUR applications) but technologies for recycling thermosets are limited, thus limiting the possible use of recycled materials in sector where these polymers are widely used.

Since the environmental benefits of recycling is well-known, no barriers have been discussed. However, the export of low-value plastics is a very topical issues since a huge amount of scraps generated during the recycling process is sent to incineration or landfilling plants.

From the legal point of view, no comments have been introduced by the interviewers.

7.3.1.3 Micro-level analysis: policy makers viewpoint

e. Activity C: results of stakeholder consultation

The activity C aims to investigate the barriers meet by policy makers in regional waste management system. Interviews to DG Environment and Economy of the Region as well as to ARPAE and COREPLA have figured out. The main outcomes are the scarcity of data and the lack of harmonization in existing legislation and unclarity of the new ones. It follows that all comments can been contextualized in the wider political and legal analysis.
Referring to data scarcity, regions (but also MSs) use different methods for calculating national recycling rates, making comparison difficult. At regional level, the municipal waste traceability is done through the ORSo (Inter-regional Waste Observatory) and MUD databases. ORSo database contains information about input-output streams of municipal waste per each regional plant. MUD database contains all the information regarding the special (commercial and industrial) waste. While the MUD database is a national instrument, ORSo database is owned by few regions[92]. The other regions consider the municipal waste management as the waste managed by CORPELA, underestimating the overall waste stream. Regarding the recycling rate, MSs could use four different methods for the calculation. Some MSs based their calculations on waste collected or sorted, while much of that waste will still be incinerated, landfilled, recycled with low quality processes or exported without guarantee of quality recycling and equivalent conditions. In this way, the final recycling process could be interpreted at the output of sorting, without fractions needing to enter a separate process. This barrier has been partially overtaken because of the establishment of a single method. However, the target summarizes the amount of waste valorized and not turned up is SPs. Moreover, the PPWD introduces a new ambiguity in the definition of the full cost recovery of EoL of packaging as part of the financial responsibility of producers under EPR. This issue is particularly highlighted by COREPLA. There is no consensus on what these costs shall cover and on what an efficient allocation of costs between producers and municipalities would be. Under most EPR schemes, PROs cover the general net costs of waste management (E.g. costs for collection, transport and treatment of waste) minus revenues from recovered materials. These net costs are not always easy to evaluate as they depend on a range of factors including the infrastructure and technology level, the quality of public services, and price fluctuations of secondary

[91] ECHA launched the Plastics Initiative in 2016. The project aims to characterise the uses of over 400 plastic additives and the extent to which the additives may be released from plastic articles.
[92] Lombardia, Veneto, Emilia Romagna, Abruzzo, Valle d'Aosta, Friuli Venezia Giulia, Campania, e Marche.

materials. In addition, the concept of "full-cost" could also refer to a range of additional expenses, such as the costs for public communication and awareness campaigns, the costs for WP measures, and the costs for enforcement and monitoring of the scheme. Finally, an additional example of misunderstanding is given by the SUPs Directive that has caused a strong reaction among the plastic and bioplastic tableware' manufacturers: the lack of clarity on the inclusion of bioplastics in the market restrictions measures has promoted the dissemination of numerous "plastic free" initiatives that substantially substitute virgin plastics with bioplastics or reusable plastic goods. From this bottleneck, the thinking about the preservation of local economy is a consequent point of discussion in the current political agenda.

As regards the complexity of WMS, unclear and overlapping roles and responsibilities of different actors, including the relationship between public bodies and PRO is under discussion. No clear information exists on who is responsible for taking care of the plastic after use and it is also pointed out by Crippa et al. (2019).

According to ERR opinion, the increase of waste generation and the low collection rates, represents a bottleneck to maximize the recycling rate. The lack of structural funds led to insufficient reprocessing capacities. This topic is also highlighted by TNO/SOFRES that identify the main barrier for higher recycling rates in the restricted market opportunities (APME, 1998). Investments are also necessary to harmonize the collection scheme and to manage it for composite and emerging plastics (E.g. PLA) that are currently challenging the recycling.

These interviews covered a particular importance because of the commitment of the ERR in publishing its own strategy on plastics with a huge financial plan aimed to push plastic recycling and reprocessing.

7.3.1.4 Meso-level analysis: value chain viewpoint

f. Activity D: results of the participative stakeholder consultation

Barriers identified at company level reflect a more complicated framework and background regarding the entire plastics value chain.

The multiple problems are investigated in a **match-making workshop** where different stakeholders have been invited to discuss together. Nowadays, the organization of events with the stakeholders covers a fundamental role in facilitating processes. As highlighted by Crowther and Donlan (2011), the most important section of the event is the so-called Value creation space that can expressed as "*a designed intersection within an infinitely more fluid process of exchange between network actors*". Representatives from Emilia Romagna Region, research centres, public and private institutions as well as plastics industry have been involved. The topic under discussion has been the plastic sustainability, encouraging prevention at first and recycling then. The main contribution has been offered by the industrial stakeholders who voiced the need to have clear legislation and robust financial support to switch the production towards more sustainable pattern. The lack of expertise on circular economy has also highlighted the need to have something able to assess the sustainability of new products, processes and supply chain.

In order to provide a blueprint of the current barriers affecting the plastic packaging value chain, **PESTEL analysis** has been performed.

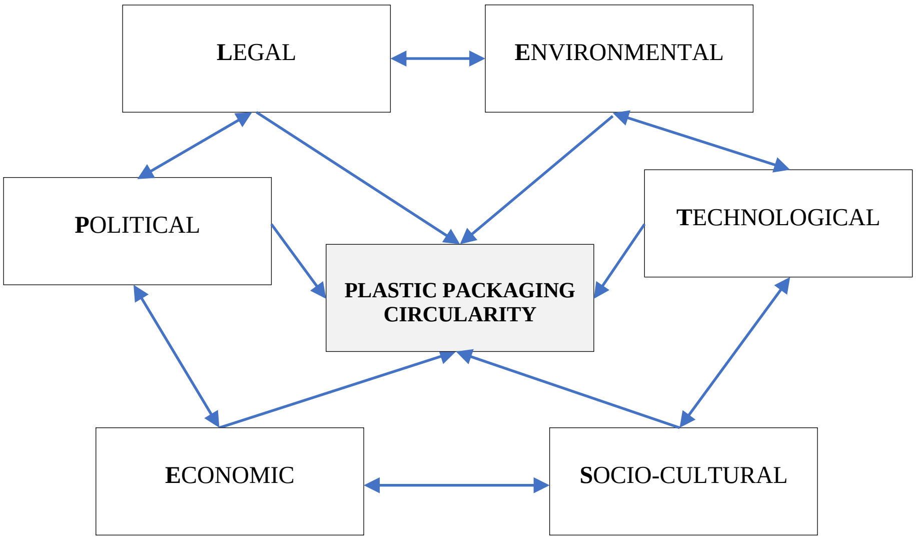


Fig. 104 Meso-level (PESTEL) analysis

As illustrated in the figure above, the following paragraphs summarize the barriers analysis across the value chain with reference to:

- Political
- Economic
- Social
- Technological
- Environmental
- Legal

aspects. As represented in the Figure 104, barriers are inter-linked.

Political and legal issues are complementary, so some key-points are discussed simultaneously. Even if eco-design guidelines support the sustainable design and production stages, specific policy instruments exist only for EEEs (European Parliament and the council, 2009). No standardization exists for recyclability and recycling of plastic packaging and PPW. This is extremely important for SMEs located in the Region that are not encouraged to invest in R&D.
The increase on additives and chemical substances on plastic articles and products has challenged not only environment and human health[93] but the recycling as well (Bartl, 2014). At legislative level, many critical issues influence the recycling scenario. The most criticized issue concerns with the REACH Regulation that doesn't not apply to waste even if secondary raw materials require a REACH Registration to get the end-of-waste status. It follows that recyclers are forced to perform chemical safety assessment (CSA) to obtain the information required to proof compliance with REACH. Another critical point affecting recycling is the case-by-case decision form to attest the end-of-waste status. The lack of harmonisation creates legal uncertainty for waste management decisions and for the different actors dealing with specific waste streams. The legal uncertainty also affects the investment decisions on new treatment capacities for the management of waste as well (Delgado et al., 2009). The misalignment between innovative technologies and BATs described in the BAT Reference Documents (BREFs) for waste treatment had additionally affected the

[93] The current risk-based approach is not adequate. Moreover, most additives currently in use are not known to have environmental or health risks and only Perfluorooctane sulfonic acid and derivatives (PFOS), Bisphenol A, some plasticizers, halogenated flame retardants and heavy metals have been identified as critical for environmental and/or health risk.

recycling plants: the recent BAT conclusions for waste treatment, published on 10 August 2018, has partially solved the problem (Commission Implementing Decision, 2018).
According to the policy makers opinion, the lack of a clear legislation, especially for the identification of waste, the calculation of recycling target and the failure to harmonize data collection and elaboration make the transition harder.
Since the MBIs are policy instruments that use the market to prevent environmental impact, the following discussion represents a link between political and economic analysis. Policymakers play a unique role in providing MBIs regarding taxations, producer responsibility schemes, green/circular public procurement etc. Twenty-four out of twenty-eight MSs currently have landfill taxes in place for waste disposal, while ten MSs have annual programmes for tax rate updates or are planning to update their rates within 2020. Just eight EEA Countries (Austria, Belgium, Denmark, France, Germany, Netherlands, Portugal and Spain) are currently implementing an incineration tax system. Tax rates varies between 2.41€/ton in Portugal and 44€/ton in Denmark (European Commission, 2012) thus reflecting the waste treatment performances. EPR, an economic instrument controlling the entire value chain, ensures that the EPR fees paid by the producers are modulated accordingly to the product's environmental impact. The 72% of EU MSs is currently developing EPR schemes over both industrial and households packaging products, while the 21% have no packaging EPR schemes at all (Institute for European Environmental policy, 2017). EPR has contributed to the creation of an efficient separate collection scheme for plastic packaging; it also has been encouraging the eco-design. However, the lack of a common approach on EPR schemes and the lack of a harmonised definition of EPR lead to inhomogeneous adoption of the system. At the end, the partial coverage of total waste management cost makes effort on the financial capital of municipal waste management (OECD, 2014). To overcome this problem, the PAYT scheme, where residents are charged for the collection of wastes based on the amount they throw away, may help to reduce the amount of waste and consequently the cost of WMS. It is seen as an impactful quantitative preventive action affecting consumers behaviour. Another element affecting consumer responsibility is the DRS that incentivises the return of used packaging through the implementation of a refundable deposit. As for now, just nine EEA Countries (Croatia, Denmark, Estonia, Finland, Germany, Lithuania, Netherlands, Norway, Sweden) are implementing DRS demonstrating the increase on collection rates for beverage containers. Among environmental tax, MSs are progressively increasing their focus on plastic reducing policies. The *Directive 2015/720 EC consumption of lightweight plastic carrier bags* has been transposed in specific national legislation by tax on manufacture, distribution of plastic bags but also fee, taxes and bans (European Commission, 2015). It has positively affected the reduction of SUP carrier bags production and consumption and therefore the performance of recycling process since films are not well-recyclable (Foschi and Bonoli, 2019; Paletta et al., 2019). Within the recent Directive on SUPs, a more impactful set of measures has been undertaken by the EC. In fact, market restriction has been established for cotton bud sticks, stick for balloons, cutlery, plates, stirrers, straws and oxo-degradable plastic food container thus pursuing the reduction at source pathway (European Parliament and of the Council, 2019). In the framework of MBIs, no instruments exist for internalize the externalities: as highlighted by UNEP (2014), the plastics price may increase by 44% on overage. However, the Italian government has established the so-called plastic tax. The tax applies to plastics converters generating a big debate. In fact, it was originally conceived as a tax of 1 EUR/kg to be applied to all plastic packaging. In order to be in line with the EC (that has included a plastic tax of 0,80 EUR/Kg for virgin plastic_based packaging) and the measures included in the Community budget, the Italian government has come into line establishing a tax of 0,45 EUR/kg for one-way packaging made of virgin plastics, thus removing recycled and bio-degradable plastics or generally, one-way packaging used to manufacture medical devices. The tax shall enter into force on July 1st, 2020 (Italian government, 2020a).

Concerning the economic issues, all the stakeholders agree on the importance of the plastic industry. The European plastics industry ranks 7th in Europe in industrial value-added contribution. It had a turnover of more than 360 billion EUR in 2018 (PlasticsEurope, 2019). Focusing on plastic converters, close to 60.000 companies works on packaging value chain (PlasticsEurope, 2019). This overview shows a great potentiality to switch plastic packaging economy from linear to circular. However, the lack of supporting legislation about circular innovations has also limited business and market. Big corporations have highlighted the fact that existing business models for the CE have limited transferability. It is also pointed out by Lewandowski (2016). Moreover, difficulties related to adaptability in countries with different culture and social behaviour make difficult the widespread diffusion of circular business models in plastic applications. Last, but not least, the risk-averse corporate climate, the lack of adequate follow-through competencies and the innovation process investments are some of inhibitors for disseminating innovative business models (Assink, 2006). About the EoL scenario, the plastic recycling industry is a complex, dynamic segment with a varied supply stream and value chain. It includes different processes: from pre-sorting, sorting, recycling to incineration and landfilling. According to PlasticsRecyclersEurope (PRE) (2015), recycling cost are the highest among all the EoL treatments. It has been confirmed by COREPLA. They are also increasing owing to the market intensification towards complex resins and products, including multi-material ones. It is additionally reflected on the price of recycled polymers that may be higher than virgin polymers, thus discouraging the market of SPs. Even if compliance scheme should support the intensification of SPs market, the financial scheme appears to be so complex as to create instable WMS. EC is boosting the SP materials usage by integrating measures on sustainability and circularity in plastic applications. Thanks to the *Regulation (EC) No 282/2008*, EFSA have allowed the manufacturing of food packaging made of recycled plastic (Commission Regulation, 2008). The recent Directive on SUPs has also forced the use of 30% of recycled in plastic beverage bottles (European Parliament and the Council of the European Union, 2019). This is affecting the price of r-PET that is considerably increased in the last months. This problem may be overcome by the establishment of collection rate for plastic bottles: being the most profitable market, a specific collection system may improve the interception of PET stream. Other aspects influence the market: technological capabilities (amount of contaminants in plastic waste stream, grade of purity of recycles, amount of plasmix are some examples) and global supply chain network (especially the landscape change in international supply chain after Chinese and Indian waste import ban) make the national and international trade difficult to be profitable. Besides, even if demand for recycled plastics is influential in the ST, oil price plays a primary role. This is also due to the lack of a system able to include externalities cost in polymers and plastics manufacturing industry. In fact, internalize the impact of externalities, should demonstrate the effectiveness of recycling from economic and environmental points of view (Crippa et al., 2019). In the end, regulatory requirements, in terms of targets and objectives, affect only the materials stream without taking into account the value and consequently, the effective supplier and demand (Di Maio, 2015).

From the social point of view, the culture and, the awareness of people about environmental issues, remains the biggest point of discussion. The lack of clear information to citizens has led to underperforming waste collection: citizens are confused about how plastics should be disposed of. The fragmentation and lack of harmonization in regulating the current collection and sorting systems is also particularly relevant contributing to ass confusion and misunderstanding to consumers. These issues affect the recycling. Resistance to change among product manufacturers and a lack of knowledge of the additional benefits of closed-loop processes have also emerged as barriers.

As mentioned above, plastics have different properties, applications and thus different recycling processes. It boosts many challenges at technical and technological level. In general, mechanical recycling and chemical recycling are possible. Mechanical recycling involves physical treatment, whilst chemical recycling treatment involves chemical feedstock (Troitsch, 1990) where polymer chains are converted to smaller molecules through chemical process (Al-Salem et al., 2009; Brems et al., 2012; Fisher et al., 2005). Technically speaking, depolymerization (chemical recycling) is not economically affordable and it is not suitable for all the resins, but it solves the many problems caused by additives and paints presence (Kang and Schoenung, 2005). In fact, some additives can have detrimental effect on the physical characteristics of recycled plastics limiting the quality of resins, the number of loops[94]. Thus, some effects of the technological barriers to plastic recycling and consequently to the remanufacturing of plastic-based products can be identified. Firstly, the use of recycled materials can become uncompetitive because of the costs of recycling process, which may require a selective collection (Al-Salem et al., 2009) and sorting (Baillie et al., 2011). Sorting is the most important step in recycling loop (Al-Salem et al., 2009). A combination of size, polymer type, colours and design characteristics influence the sorting rate. The proper identification of materials is essential for achieving a maximised purity of recycled materials. In addition, it should be considered that different materials, combined in a multi-layer configuration, lead to a problem of incompatibility: each resin is characterized by its own melting temperature, as function of the crystallinity phase and molecular weight[95]. Therefore, different resins characterized by differences in crystallization temperatures develop discontinuities which could represent defects in the final object.

The discussion on environmental issues is firstly highlighted by the huge amount of scraps, generally plasmix, generated during the selection and recycling processes. Scholars are working on searching for solutions in the field of chemical recycling. The debate on how properly manage these wastes is still open (Astrup et al., 2009). As already mentioned, four chemical methods exist to threat plastic waste. Pyrolysis is the most appropriate technology to convert mixed plastics into tar oil which can be cracked down and further refined for new plastics production (CE Delft, 2019), however the economic feasibility and the environmental impact should be examined.
Life cycle assessment (LCA) is the main instrument to measure environmental impact, but it is clear from the literature that LCA is ineffective as a provider of precise quantitative information (Nakajima et al., 2000; Lee and Xu, 2005). It is more challenging when systemic thinking in CE models must be evaluated: many simplifications undermine the potentials of using LCA to quantify the environmental performances of products in multiple loops (Niero et al., 2016). These issues have been warned by EC at such a point that an EU platform on LCA has been inaugurated in January 2018 and many stakeholder's consultation are ongoing.

From the legal point of view, the cases of illegal trade and disposal of plastic waste are growing. According to the study *Ecomafia 2019. Le storie e i numeri della criminalità ambientale in Italia*, about 8.000 cases of illegal waste management were registered in 2018[96] (Legambiente, 2019). However, the national law 68/2015 on eco-crimes is giving a strong contribution to appeal illegal disposal, fires, trade etc.

A summary of the outcomes resulting from the PESTEL analysis is reported in the following table.

[94] Decontamination technologies and processes to remove additives exist but implementation is still limited (Crippa et al., 2018).

[95] The mould temperature per plastic resin are here listed.

Tab. D. Mould T per plastic resins

Material	Mould T [°C]
ABS	90-180
Nylon 6	100-180
PET - Bottle	60-120
PO	50-150
PS	150-220
PVC	50-120
SAN	70-120

[96] It includes all types of waste, with relevance to construction and demolition waste as well as industrial sludges.

Tab. 36 Summary of meso analysis outcomes. PESTEL analysis

	Political	Economic	Social	Technological	Environmental	Legal
Production	Lack of alignment between new technologies and BATs Diffusion of plastic-free initiatives (not in line with the SUPs Directive) Lack of eco-design Directive for packaging	Influence of the oil market on the virgin polymers price (and consequently recycled plastics) High price of rPET Volatile market of SPs	Lack of expertise and knowledge on CE	Increasing complexity of plastic packaging design Growth in the usage of additives	Impact of possible hazardous substances included in the SPs stream	
Consumption	Multitude of in eco-labelling generating confusion among consumers	Cost of sustainable products	Inert behaviour towards innovation Urban littering Lack of product service systems			
Waste Management	Fragmentation of recycling value chain Absence of information on chemicals included in waste (REACH Regulation) Complexity of WMS Blocking of EoW criteria Data scarcity Lack of harmonization in data collection and elaboration	Lack of harmonization in MBIs for waste disposal in Europe Lack of harmonization for PAYT system in Europe Lack of harmonization for DRS in Europe Lack of investment in recycling infrastructure High cost of recycling Increase of incineration cost (as consequence of the Chinese waste import ban)	Confusion in correct waste collection	Lack of recycling infrastructure capacity to treat local plastic waste No separated collection for hard plastic goods Contamination in waste stream Lack of technologies able to sort black polymers Low recycling performance because of complex packaging design	High generation of plasmix and impact of its disposal High environmental impact of chemical recycling	Illegal trade of plastic waste Illegal plastic waste disposal Illegal fires in storage sites
Life cycle	Complexity of EPR scheme Lack of harmonization of EPR governance in Europe Lack of alignment between product, chemicals and waste legislation	Competition between virgin and recycled polymers price Limitation in circular BMs Lack of expertise in CE models Ambiguity in financial cost of EPR scheme		Low purity grade of SPs	Limitation of LCA studies	

7.3.1.5 Macro-level perspective

The problems about recyclability, recycling and circularity of plastic packaging may be assigned to a wider picture describing the urgency to make something to improve the sustainability of plastics applications and their usage along the value chain.

It is well-know that plastics are energy-saved materials compared to other: most plastic products need less energy to be produced than their alternatives (E.g. steel and iron), and additionally many plastic products save significant amounts of energy during the use phase (Pilz et al., 2010). Plastics have a carbon-intense life cycle. According to OECD (2018), the emissions from plastics in 2015 were equivalent to nearly 132 Mt of CO_2 anyway (See Figure 105). This number is expected to grow, projecting that the global demand for plastics will increase by some 22% over the next five years. This is mainly due to the consideration that plastic is currently an extremely versatile low-cost material. In this BaU scenario, emissions from plastics will reach 43% of the global carbon emission by 2050 (OECD).

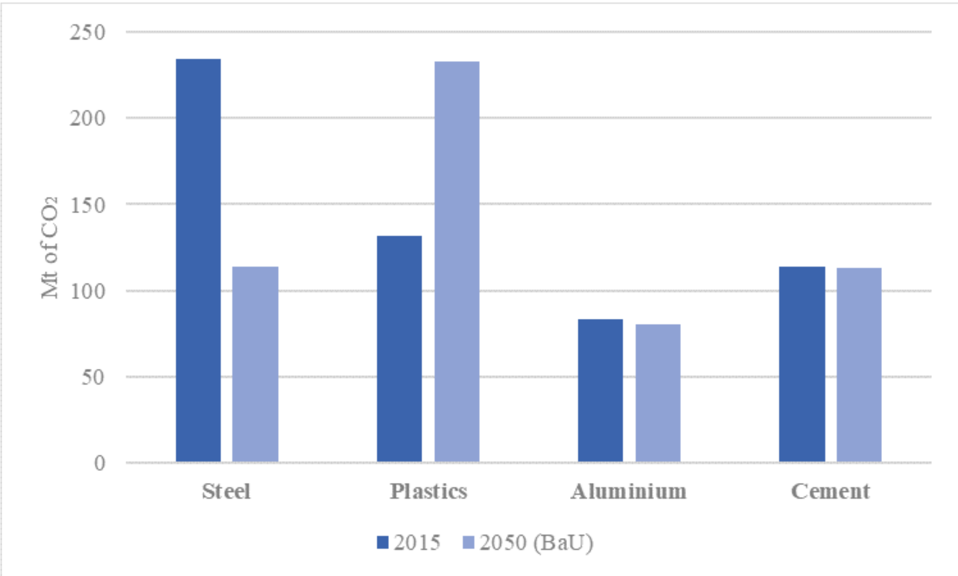


Fig. 105 Comparison between present situation and future scenario (BaU) for steel, plastics, aluminium and cement carbon footprint – Source: OECD, 2018

Many studies highlight that recycling of plastic waste compared to waste incineration and landfilling proved to be the preferred option for all impact categories (Lazaveric et al., 2010). The LCA performed by Perugini et al., (2005) quantified emissions savings of 70% to 80% in the recycling scenario respect to the virgin plastic production scenario. The details on the GHG emission factors for plastic resin are provided by PRE (2015) as illustrated in the table below.

Tab. 37 GHG emission factor of recycling and virgin plastics production. Analysis per plastic resin. Source: PRE, 2015. Data for PET, PE-HD, PE-LD come from the Wisard LCI. For other resins, the GHG emission factor is assumed equal to that of PE.

Direct GHG emission [kg CO_2 per t of plastic)	PET (bottle/fibre)	PE-HD	PE-LD	PP	PS	PVC	Other plastic resins
From recycling	510/280	348	348	348	348	348	348
From virgin plastic production	2150/2050	1800	1870	1630	3300	1900	4800

If products are designed according to recyclability requirement, CO_2 saving may be higher. In addition, more plastic recycling helps to reduce Europe's dependence on imported fossil fuel and exported plastic waste. This supports efforts on decarbonisation and creating additional opportunities for growth thus being in line with commitments under the *Paris Agreement* and the *Agenda 2030*.

7.4 Strategic problem orientation and gap identification

Once the vision of the future has been formulated (according to the normative landscape in this case), and the guiding principles have been established (following the decoupling concept in this case), the study has required a comprehensive analysis of the current situation (the so-called system knowledge) as starting point to define the next steps. The work provides better results if relevant stakeholders are involved (Jacob et al., 2004). Therefore, problem definitions, main unsustainabilities, opportunities, and possible solutions have been tackled by the participation of the main stakeholders involved in the process. The present situation understanding has served to identify gaps and needs (Robinson 1990; Vergragt and van der Wel 1998) and in particular to explore the problems from a systemic point of view. The stakeholder opinions have facilitated the identification of the current gaps between a sustainable future and the present situation, and to look backwards seeking for ideas, leapfrog technologies and trend breaches (Aart, 2000). The strict communication among stakeholders has motivated and stimulated each other to overcome current obstacles.

This step helps to get into the details of the context and orientate the problem with the aim to set up an efficient strategy. The problem orientation is carried out through the **Context map** accomplishment. The Context Map is a visual tool based on the technique PESTEL1 (Aguilar, 1967). It considers the political, economic, social and technological challenges already described and adds the analysis of the trends as potential drivers for change. The context map collects outputs resulting from the micro (inside perspective) and meso (outside perspective) level examination and contribute to the **Inside of Outside analysis**. While the Outside perspective gets together the considerations already described, the Inside analysis is strictly linked to the objective of this work.

The map is illustrated in the Figure 106.

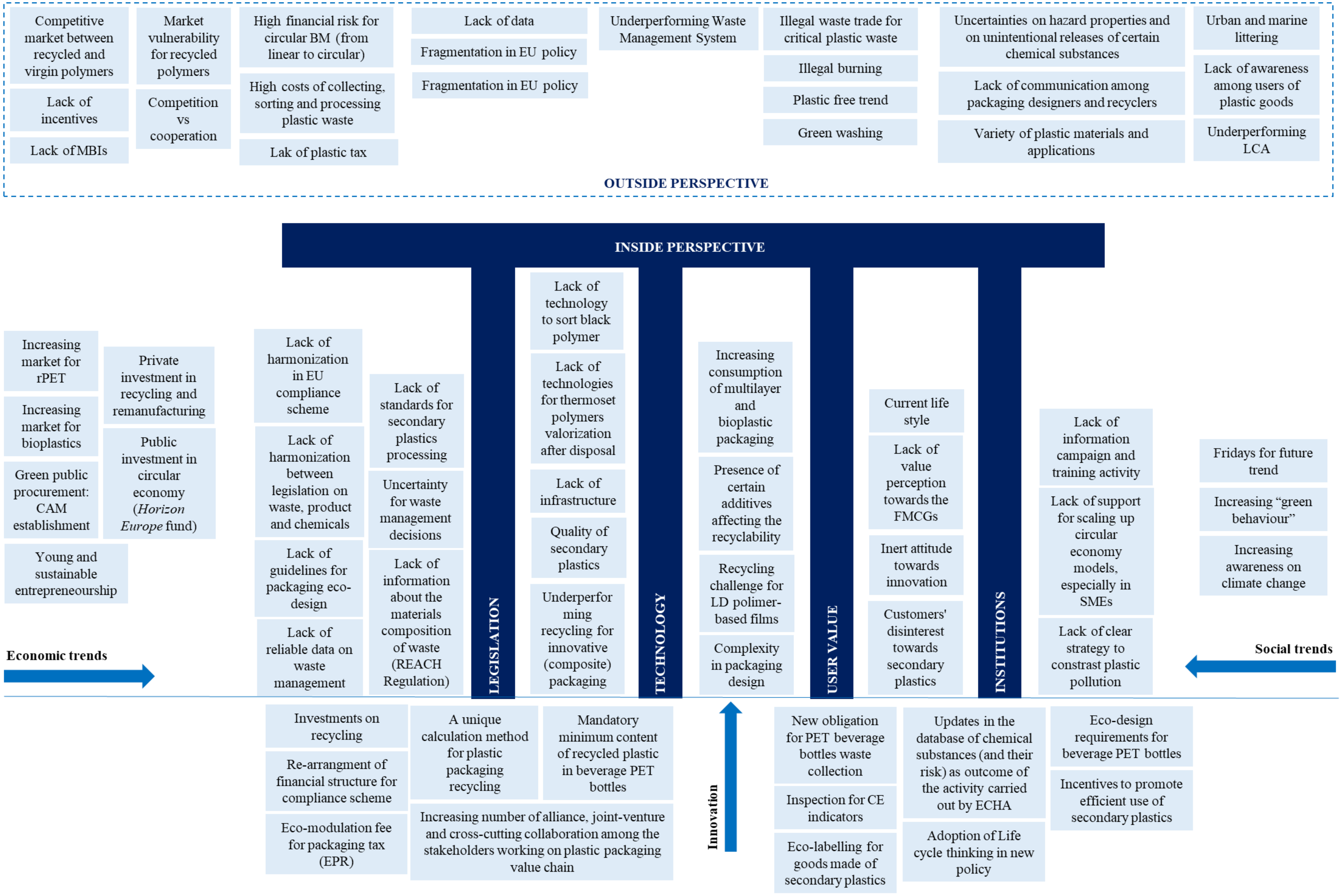


Fig. 106 Inside of Outside analysis. Context map

The Context map helps to understand how the system around the challenges works. It gives an idea about the current state and the direction of establishing a better position to make decisions, adopt a strategy or navigate through the system. Consequently, the map spots opportunities or significant threats that are summarized in the **SWOT analysis** (See Table 38).

Tab. 38 SWOT Analysis

STRENGHTS	WEAKNESS
Specific policy on plastics	Lack of communication among stakeholders
Adoption of Life cycle approach in *Circular economy package* and *Plastics Strategy*	Lack of knowledge and expertise in circular economy
Introduction of eco-modulation fee for packaging tax	Lack of incentives
Increasing SPs demand	Complexity of WMS
Introduction of a unique recycling rate calculation method	Differences in EU EPR schemes
Dissemination of eco-design requirements (including the RECYCLASS tool)	Lack of quality standards for sorted plastic waste and recycled plastics
Establishment of minimum recycled PET contents in beverage bottle manufacturing	Price of SPs[97]
Private and public investments through join-venture and alliance	Limitation of LCA
	Lack of a coherent legislation across Europe
Alliances and cross-cutting collaboration	Lack of systemic thinking
Radical change in production-consumption-disposal patterns	Competition with oil-industry
Claim of after-use plastics economy	Complexity in plastics circularity issues
Traceability of plastic waste management	Lack of interest
Standardization for plastic packaging design	Inability to harmonize plastic packaging design
Better performance of plastics recycling	Lack of data on WMS
Higher performance of plastics remanufacturing	Inability to measure circularity performance
Efficient metrics for plastics circularity	Green washing
OPPORTUNITIES	**THREATS**

Embracing the future_oriented concept, the SWOT analysis allows to identify the opportunities and therefore the strategy to adopt. A greater integration of recycling activities into the plastics value chain is essential and may be facilitated by the cross-cutting collaboration between plastics designers, manufacturers and recyclers. At the moment, this consideration is not possible to be made since no information about the amount of SPs remanufactured and used by compounders and/or converters are available (See Figure 107).

[97] Since recycled food-grade packaging typically uses plastics from PET beverage containers, the food-grade rPET demand (and price) is higher compared to other resins.

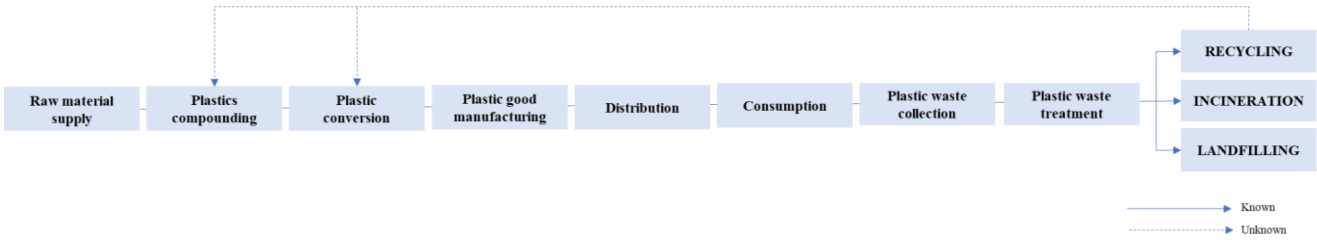


Fig. 107 Plastic packaging value chain in a closed-loop system

However, it is possible to identify the means to use as fundamental elements to design the strategy.
It entails a matchmaking between industry commitments and policy interventions in three fundamental steps:

- **design**
- **recycling**
- **re-manufacturing (circularity)**

The product design and the development phase influence more than 80% of the cost connected with a product, as well as 80% of the environmental and social impacts (Charter and Tischner, 2001). Consequently, the design stage acquires significant importance for the contribution to barriers mitigation as well as cost reduction and environmental impact minimization (Matsumoto et al., 2016). During the design phase, plastic products must be manufactured taking into account their entire life. Economic incentives such as eco-modulation fee may attract designer and favour circular products and business models (Institute for European Environmental policy, 2017). The need of a common approach on designing may contribute to standardize the plastic packaging good. This means minimizing problems during the sorting, extruding and reprocessing processes. The changes may also enable higher plastics recycling yields. In addition, the recycling throughput should be monitored in order to get the exact amount of plastics properly recycled. The monitoring activity helps to analyse the recycling performance over the years and therefore assess the contribution of design on that performance. The link between packaging manufacturing and EoL has already established by the PPWD through the application of the EPR principle; however, it doesn't connect stakeholders estimated to close the system in a circular loop. Additional efforts are needed. The connection is represented by the co-creation of eco-design requirements that meet the needs of both. Once the recycling performance have been optimized, the critical issues regarding the SPs should be reduced and the market of SPs should considerably improve. The plastics reprocessing, and therefore the increasing introduction of recycles in high-value products will allow to close the loop and maintain the value of plastic materials higher and higher. Since the reprocessing is also regulated by the market rules, a metrics promoting the SPs usage should be implemented. Value_based indicators may encompass the limited information provided by the recycling rate that is a mass_based indicator. It is extremely important in plastic fields where a variety of materials compositions and applications exist. It may trigger an incentive effect on recyclers to take care about the quality of SPs. In fact, a true CE will only be achieved if materials contained in EoL-products are comprehensively recycled at a quality which enables again their use in new products (upcycling). And a prerequisite for this is the quality which combine high technical performance (i.e. range and yields of reclaimed materials) with sound environmental, health and safety condition. This indicator speeds up the generation of high amount and recognizable quantity of SPs. At this point, the recycling yield should be based on the amount of plastics effectively turned up into new applications and not on the amount of plastic waste sent to recycling.

8 CIRCULARITY STRATEGY

8.1 Strategy set-up

As highlighted by Verghese and Lewis (2007), packaging is sustainable if meets functional requirements and rationalize the resources (including materials, energy and water) throughout its life cycle. This means implementing a cyclic use in compliance with the people safety and the natural environment safeguard. This work emphasizes the sustainability of packaging as recyclability in order to maintain the value as long as possible and add value itself in multiple reuse cycles.
The previous discussion has figured out the multitude of stakeholders involved in the packaging value chain and the huge number of barriers hindering the sustainability (and recyclability. in this case) of plastic packaging. In order to optimize the recyclability, design and effective recycling should be linked and analysed in combination with economic viability, technical performance, legislative obligation and function As already illustrated, a variety of legislative measures, technological innovations, societal needs and market trends are promoting the rethinking of packaging rethinking. The main driver is represented by the EC whish is speeding up circularity through a systemic vision through the EU targets and goals establishment for 2030. The Commission wants to achieve the ambitious goal about having 100% recyclable (or reusable) plastic packaging and 55% of recycled plastics. This means adsorbing 10 Mt of plastics which is more than twice the current volume circulating in Europe. The trend is similar at regional scale. In the region 91.581t should be additionally recycled if nothing gets done. It follows that Europe (and consequently MSs and regions) must increase the ability to convert large volume of after use plastics to recognizable high quality recycles. In order to do that, it needs a completely change of the current production, consumption, disposal patterns and a life cycle thinking. This last principle is necessary to reduce impacts and externalities along the value chain. Designing by thinking about the role of packaging in each step of its life helps to overcome the critical issues caused by innovative packaging that has been considered sustainable from the resource efficiency perspective but has created more complicated problems from other perspectives (E.g. EoL). An example is given by the bio_based plastic goods: this material is considered sustainable because of sourcing from renewable resource but their intrusion in the conventional plastic WMS compromises the performance of the recycling process. The correct valorization will rather add value to organic and biological streams. Another example is offered by the lightweight multi-layer packaging that has reduced the product weight but complicated the design manufacturing and consequently, the materials' sorting and valorization. Therefore, the lack of a full cycle thinking within the system leads to unintentional negative consequences that exceed the benefit brought by the innovation. Another issue regards the final step of the EoL: as pointed out by several LCA studies, environmental benefit only exists when the recycled plastics replace virgin resins (Shonfield, 2008). This means that downcycling does not make sense from an environmental point of view (Rem et al., 2009). It follows that, in order to integrate circularity with sustainability, upcycling is the building block of the following strategy. Finally, since chemical recycling is not well-established nowadays, only mechanical treatments are here considered.

Strategically speaking, prevention must be prioritized to recycling. The present work has focused the attention on material recovery for those items that cannot be substituted with the aim to maintain value as much as possible. The value maintenance is highlighted by recyclability as well as recycling. In this way, qualitative prevention, intended as the reduction of the impact of generated waste, is pursued. Added value is created when upcycling is pursued. A clear and robust path to reach that goals has not been provided until now. Many critical issues affect the packaging recyclability, recycling and circularity. The lack of knowledge and expertise, the fragmentation in data collection, the unclarity of legislation and the complexity of WMS are only some of the questions that have been experienced in the participative process. This preliminary work has contributed to set up the so-called **Circularity strategy** that should provide an action plan to fulfil the gaps between the present situation and the future scenario (See Figure 108).

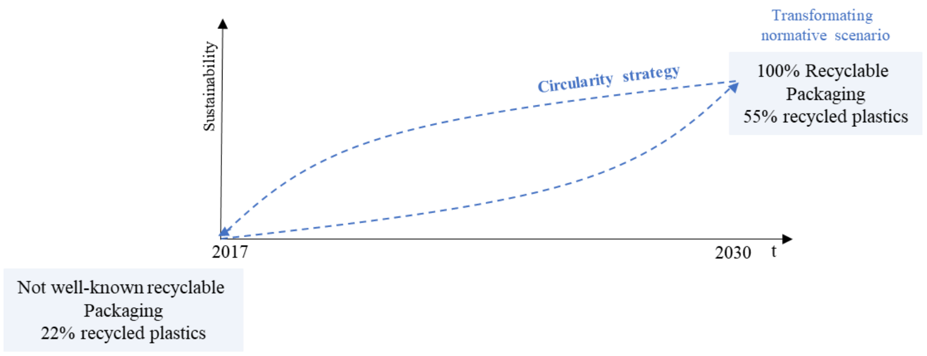


Fig. 108 Circularity strategy

The Strategy is built up to support the recycling and recyclability of those plastic packaging that are collected for material valorization and supported by legislative mandatory program.

As shown in the Figure 109, the start and end points need of a robust plan to become closer. The Circularity Strategy captures the dynamics of the current system in order to perform a certain reconfiguration able to redistribute roles and responsibilities. It includes three pillars here illustrated.

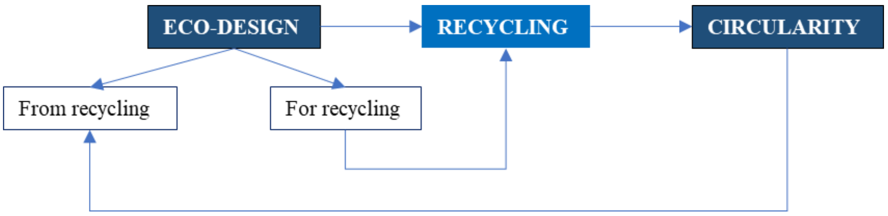


Fig. 109 Circularity strategy, pillars

Eco-design and recycling may be considered as the means to speed up the circularity of the system represented in the Figure 109.
While the first element aims to fulfil the product_level goal, the second and third elements aim to maximize the recycling yield from the material and economic value. Since the value of SPs is affected not only by design but also the recycling infrastructure, the real recycling yield should be considered. However, the quantity is not a enough to assess the performance of recyclers. In fact, just producing more secondary raw materials does not guarantee it is taken up in products (Hahladakis et a., 2018). Quality should be considered. The increase in value will boost the upcycling and in particular the use of recycled plastics in high-value applications such as the packaging application. The growing demand of SPs in packaging applications will foster the after-use plastics economy.
As shown in the Figure 110, the eco-design is the mean to boost higher recycling performance, that considers quantity as well as quality. These factors, together with the presence of a consistent recycling infrastructure, will speed up the recycles and uptake the recycled content in a well-functioning market where SPs will substitute the virgin ones.

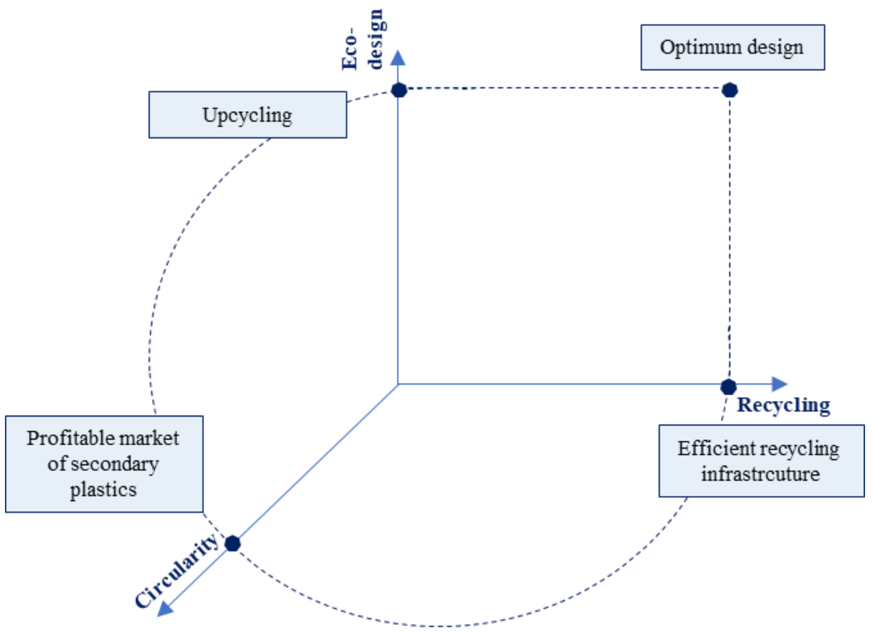


Fig. 110 Circularity strategy, connection between eco-design, recycling and circularity

From the operational point of view, two practical elements are combined. The following sections summarise the content of an apparatus that is intended to have a supporting function in improving recyclability in one side and recycling (and circularity) in another. The approach here adopted goes beyond focusing on a specific site or product and embraces the whole system in a LCT. While system thinking leads to socio-technical innovation encompassing the technological one and connecting social and economic aspects too, LCT thinks about the value chain of a product (Pajula et al., 2017)

The first element includes requirements to design a recyclable plastic packaging. The barriers analysis has pointed out a lack of knowledge on it, especially in SMEs. The purpose is to support the regional packaging designers and manufacturers to rethink their packaging in accordance to the existing governance and infrastructure getting effort to recycle that packaging. In fact, the tool supports the fulfilment of the recyclability criteria established by CONAI and COREPLA in the field of eco-modulation fee characterizing the packaging tax (the so-called CAC explained in the paragraph 3.4.1.1). As suggested by Ellen Mac Arthur Foundation (2016), recyclability aspect should be encompassed in the performance criteria of such a product, together with safety conditions, technical aspects, marketing etc. This tool paves the way for this inspiring idea too. In addition to DforR, design from recycling (DfromR), intended as the re-processing of SPs in new products, is here considered. Since the design from recycling is not-well searched yet, this part of the tool wants to attract manufacturers to rethink the supply chain providing an overview of legislative and economic incentives.
Since this strategy and the related basing tool are the results of a long process, the eco-design tool may solve many critical issues met by the stakeholders working in the plastic packaging value chain. The following table show the advantages that this item may bring to the system.

Tab. 39 GAP analysis concerning eco-design

Background	ECO-DESIGN for RECYCLING from RECYCLING →	Foreground
Inability to harmonize plastic packaging design		Provide a tool aimed to harmonize product design and manufacturing
Lack of systemic thinking		Provide a life cycle_oriented tool
Lack of knowledge and expertise		Provide a tool supporting designers and converters to rethink their packaging
Lack of communication among stakeholders		Connect converters and recyclers in order to solve critical issues at design as well as EoL stage
Limitation of LCA		Overcome the limits affecting LCA by providing a tool integrating technical issues with economic and legislative ones in LCT approach
Lack of standardization		Provide a unique guideline for plastic packaging that may improve the standardization in packaging manufacturing
Differences in EU EPR scheme		Harmonize eco-modulation fee in accordance to eco-design requirements
Green washing		Identify real commitments on sustainability
Lack of interests		Incentivize inert stakeholders through economic incentives (E.g. eco-modulation fee on packaging tax)

According to PRE, recyclability should take into account whether the item, when put on the market, is collected for recycling, has market value and or is supported by a legislatively mandated programme to ensure it is sorted, recycled and made available as new resource. The recycling rate gives information on the mass recycling rate excluding the quality for recycling volumes and the possible usages of recycled materials for new valuable purposes. As highlighted by Di Maio and Rem (2015), this has led to inaccurate and misleading considerations, which have contributed to feed the market with wrong decision making and poor innovation (See Table 41). The circularity element aims to introduce value_based indicators representing both the quality and the quantity of recycled mass.

Tab. 40 GAP analysis concerning the circularity

Background (gaps)	VALUE_BASED INDICATOR FOR CIRCULARITY →	Foreground (benefits)
Inability to measure circularity performance		Provide a robust metric for plastics circularity
Price of SPs		Provide more information on the value of SPs
Price of SPs		Improve the SPs market
Lack of standardisation for quality standards of sorted plastic waste and recycled plastics		Support EoL processes' standardisation
Lack of incentives		Promote an after-use plastics economy
Complexity of WMS		Identify the stakeholders having a pivotal role in recycling

The following paragraphs describe each element here introduced.

8.2 Recyclability: the role of eco-design

8.2.1 Background

Eco-design covers the pivotal role in pursuing the circularity of plastic:based applications. Hahladakis and Iacovidu (2019) write "*plastics can only be recycled economically if recycling is built into their design*". Since its first definition by the Rathenau Institute (Brezet et al., 1997), eco-design is considered as useful methodology able to capture a holistic vision (combining aesthetics, functionality, quality, manufacturing, economics and environmental issues). According to the targeted objectives of a product or process, **Design for X (DFX)** groups vary typologies of designing where X stands for a particular eco-design strategy (Holt and Barnes, 2010). When the design take care about environmental concerns, the DFX is intended as Design for Environment (DfE) (Tukker et al., 2001). When practices aimed to improve EoL performance are implemented, DforR may be adopted. DforR should be considered separately from other strategies, including Design for Manufacturing (DfM) and Design for Remanufacturing (DfRem) (Bras and McIntosh, 1999). In the framework of DforR, a variety of eco-design guidelines exist nowadays. Just to name a few, WRAP (2013) has published a guidance document named ***Design of rigid plastic packaging for recycling***[98]; the British Plastic Federation (BPF) has suggested its own guidelines entitled ***Recyclability by design***[99]; ECOS (Le Blevennec et al., 2019), with the collaboration of VITO and ÖKOPOL, has published the report ***For Better Not Worse: Applying Eco-design Principles to Plastics in the Circular Economy***; the ***Design for Guide for Plastics Recyclability*** has been performed by the Association of Plastic Recyclers (APR)[100]; the **European PET Bottle Platform (EPBP)** has promoted its own rules regarding the best practices for PET bottles recycling[101]. Moreover, a multitude of technical tools have been set up: ***Pack4ecodesign*** is designed

[98] WRAP has also created a web-based tool for PET Bottle Categorization.
[99] Brithis Plastics Federation – Source: http://bpf.co.uk/eco-design
[100] Association of Plastic Recyclers – Source: https://plasticsrecycling.org/apr-design-guide/apr-design-guide-home/99-apr-design-guide
[101] https://www.epbp.org/design-guidelines/products

by FostPlus[102], **Recyclass** is published by PRE[103]. Other tools have been mapped and analyzed by OECD (2018) considering factors such as type, purpose, accessibility and update frequency of the tool as well as the input-output data. Among them, it is worth mentioning the tools named ***Flame Retardant the Systemic Assessment, CES Selector*** **and** ***SolidWorks Sustainability***. At national level, the Italian technical law UNI EN 13428:2005 (2005) regulates packaging manufacturing promoting all possible measures reducing the environmental impact. No guidelines exists for DfromR.

8.2.2 Structure

As aforementioned in the previous discussion, eco-design represents the first step for optimizing the recycling performance of plastic packaging. As listed in the paragraph above, many eco-design guidelines exist. However, if eco-design aims to optimize the recycling, it must be linked to the local infrastructure and governance. A variety of factors affect the recyclability of plastic packaging and a unique eco-design model doesn't exist. In fact, what is recyclable in Italy cannot be recyclable in another MS. It depends on the organizational management as well as technological innovation. The application of the participative backcasting method has been extremely useful to design an efficient eco-design tool. This eco-design tool contains multiple information to optimize the design of the packaging by minimizing the impact throughput the life span and maintaining the higher value through recycling and reprocessing. In order to avoid misleading indications, the tools incorporate general eco-design requirements into local system. Moreover, the technological aspects have been integrated to the legislative and economic ones as the system thinking requests.
While the technical requirements are sourced by the Design by Recyclability report published by BPF (2018), the European PET Bottles Platform[104], the RECYCLASS platform[105] performed by PRE and of course, the national eco-design guidelines published by CONAI[106], the technological are investigated through the Activity A explained above. The inventory of the technological apparatus present in the regional infrastructure allows to better understand the EoL scenario of the plastic packaging disposed of in the region. Open bags machinery is adopted for those facilities managing municipal waste, magnetic separators is present in all the WMF, NIR optical sorters are in the majority of the plants as well as the shredders. Not all the facilities have the washing and blowing plants. Finally, manual sorting is already present everywhere in the Region.

Indeed, the legislative measures refer to European as well as national and regional initiatives, such as:

- the Circular economy packages
- the SUPs Directive
- the REACH and CLP Regulation
- the so-called EU Delegation law (that transpose the CE package into national policy)
- the Legislative Decree 39/2016 (that transpose the CLP Regulation into national policy)
- the Legislative Decree 205/2010 (that transpose the WFD into national policy)
- the legislative Decree 152/2006 as amended by the Legislative Decree 205/2010 (that transpose the PPWD into national policy)
- the Ministerial Decree 264/16 on by-products valorization
- the regional law 16/2015 on circular economy

[102] https://www.pack4recycling.be/en
[103] https://recyclass.eu/it/
[104] European PET Bottle Platform – Source: https://www.epbp.org/design-guidelines/products
[105] PlasticsRecyclersEurope – Source: https://recyclass.eu/
[106] Ecodesign guidelines for facilitating the plastic packaging recycling – Source: http://www.conai.org/wp-content/uploads/dlm_uploads/2017/07/Linee-Guida_Riciclo_Plastica.pdf

Since the 100% recyclable or reusable target is nor composed of mandatory measures, economic incentives has been set up to incentive designers towards the eco-design. The economic aspects include the framework of taxes and incentives established for plastic packaging and sustainable plastic packaging. In case of DforR, the only item is the packaging tax as application of the EPR principle. In case of DfromR, the proposal on the VAT reduction in case of a minimum 30% recycled content in new products, is ongoing. Indeed, the minimum criteria environmental (including minimum content of PCR plastics in packaging) for GPP are already operative. And also, the very recent plastic tax may foster more and more packaging manufacturers to uptake recycled content in their manufacts.

The functions covered by the eco-design tools aim to meet the needs expressed by the stakeholders during the participative process[107].
The main functions are here listed:

- Helping plastic packaging designers and manufacturers in evaluating their products, understanding how efficiently they are designing and producing and how sustainable they are at the EoL in accordance with the existing governance
- Supporting plastic packaging designers and manufacturers to understand how to improve the recyclability or rethink the product according to the recyclability principle
- Incentivizing plastic packaging designers and manufacturers in incorporating PCR materials through economic instruments
- Facilitating decision making in directing investment through the provision of a comprehensive analysis of the current regional plastic packaging landscape

At this stage of the work, ERR and the regional converters have shown their interests in having a tool supporting design rethinking in one side and providing an overview on the current innovation in regional plastic packaging sector in another. The tool is intended to be able to act as an efficient monitoring instrument and data hub, able to reflect the needs of manufacturers as well as of regional authorities. The region will be highly advantaged by the promotion of circularity. Indeed, this can provide at regional scale all the benefits related to CE implementation, as stated at EU level: market competitiveness, jobs and economic development (European Commission, 2019e).

8.2.3 Configuration

For the purposes of this tool, two main principles drive the structure of the question-based tree:

- **Design for recycling**
- **Design from recycling**

While the first outlines the level of recyclability of the plastic packaging and the possible reduction on the packaging tax (CAC) in accordance to the requirements established by the CONAI, the second incentivizes converters to use more and more recycled plastics because of the environmental as well as economic benefits that, in this case, is represented by the plastic tax and in future, the reduction in the VAT as proposed by the Quality Recycling Working group composed of the national Agency for Environment (ENEA), COREPLA, CONAI, Rubber-Plastic Federation and the environmental organization Legambiente. The tax is 0,45 EUR per kg of virgin plastics used in MACSI (with the exception of medical device packaging, compostable plastics and recycled materials). The Working group has proposed a reduction in VAT if converters manufacture product using at least 30% of recycled plastics. An additional stimulation is given by the criteria established within the GPP PAN.

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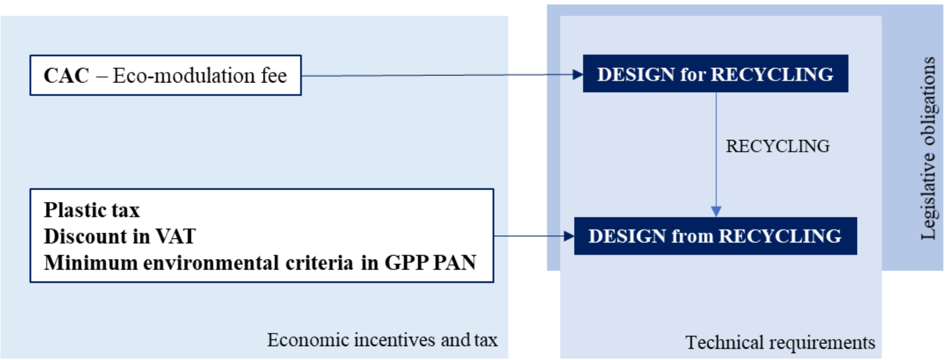


Fig. 111 Eco-design tool. Multi-criteria structure (general)

A schematic representation of the **layout** is shows in the table below.

Tab. 41 Eco-design tool. Multi-criteria structure (detail)

Primary, secondary, tertiary packaging

			FCM SUP	FCM Not-SUP	Not-FCM SUP	Not-FCM Not-SUP	Bottles	Other containers	Thermoforms	Films	Boxes and crates	Commercial and industrial	Sortable and recyclable with the current technologies	Other Sortable and recyclable	Not-sortable and recyclable
DESIGN FOR RECYCLING	Legislative	CIRCULAR ECONOMY package	x	x	x	x									
		REACH Regulation	x	x	x	x									
		Food packaging Regulation	x	x											
		Directive on SINGLE-USE PLASTICS	x		x										
	Tech.	Rigid					x	x			x				
		Flexible							x	x					
	Econ.	Tax on packaging (Cat A)										x			
		Tax on packaging (Cat B1)											x		
		Tax on packaging (Cat B2)												x	
		Tax on packaging (Cat C)													x
DESIGN FROM RECYCLING	Legislative	Directive on SINGLE USE PLASTICS													
		GREEN PUBLIC PROCUREMENT													
	Tech.	Eco-labelling (E.g. EuCertPlast, PSV)													
	Econ.	Plastic tax													

A literature review has allowed to summarize some common rules for designing recyclable plastic packaging, as listed below:

- Avoid small format and heavyweight.
- Enhance the design for disassembling.
- Prefer single resin than multi-composite material[108] and minimize the use of auxiliary components made of non-plastic materials. Consequently, glass and metals[109] are strongly discouraged (CONAI, 2017). In case of plastic_based packaging, it is preferable that the main polymeric constituent represent at least the 80% in weight of the whole packaging[110]. If multi-layer packaging is not avoidable, it is preferable to adopt resins that can be separated by density[111] (CONAI, 2017).
- Avoid or minimize the use of inks and pigments that are difficult to remove. Direct printing is preferable only in case of colored packaging because of the reduction in sleeve and glue usage. In other cases, direct printing must be avoided. If it is not possible, direct printing should not cover more than the 50% of the total surface. In accordance with the EU Printing Ink Association (EuPIA), inks must be not toxic and they must not bleed and dye into a washing solution.
- Avoid or minimize the use of coating or barriers. If it is not possible, differences in densities are preferred in case of plastic barriers and/or coatings. Nylon, EVOH, PVDC and PA coatings are detrimental for the majority of polymers in the recycling process (WRAP, 2013). For multi-materials packaging, if aluminum layer is adopted, it is necessary to ensure that the thickness is <5µm in order to avoid that the eddy-current separator can allocate the material to aluminum waste stream
- Avoid or find alternatives to the usage of additives. Chalk ($CaSO_4$), talk powder and marble ($CaCO_3$), foaming agents and fillers change the density of polymers causing a wrong sorting in the water-based float sink system. Bio/oxo/photodegradable additives and nanocomposites must be avoided (WRAP, 2013)
- Prefer light and clear colored resins, facilitating sorting and reprocessing activities. Black packaging cannot be detected by NIR technology; therefore, the use of Carbon Black[112] is strongly not recommended (WRAP, 2011).
- Avoid or reduce the dimensions of labels and sleeves with a maximum of 40% of the total surface for PET bottles (EPBP, 2018) and 60% for trays
- Avoid PVC[113], paper and metallized labels which negatively affect the sorting by floating process. The label should preferably be of the same resin type of the main body. In case of PET, it is necessary to adopt a notable difference in density[114]

[108] Current sorting technologies recognize only the external layer of the plastic product; it follows that multilayer (with external plastic layer) plastic packaging is detected in the same way of monolayer plastic packaging stream.

[109] Metallic components cause problems both at the plants (and in particular at the blades of the machines) and at the product (metallized films create holes during the extrusion).

[110] The difference in weight allows to separate the main body from the other components of the packaging.

[111] The polymers' separation is carried on through the flotation process.

Tab. e. Behaviour of polymer in water

Behaviour in the flotation process/Polymer	PP	LDPE	EVA	HDPE	PS	PA	PVC	PET
Floating	x	x	x	x				
Sinking						x	x	x
Variable					x			

[112] Carbon black is a material produced by the incomplete combustion of heavy petroleum products. In plastic application, it is used as a colour pigment.

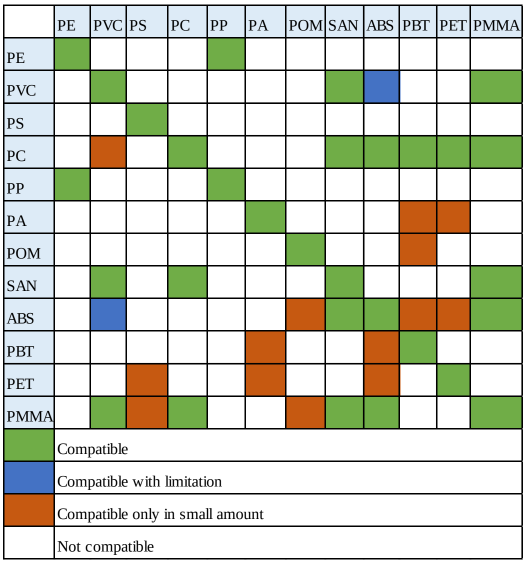
[113] A small percentage (such as 0,0005% by weight) of PET resin impacts strength and clarity and makes it brittle and yellowish.

[114] The polymeric composition of packaging design influences the recycling performance because of the polymeric compatibility.

Tab. f. Polymers compatibility

- Caps and lids should remain attached to the container during its usage (as stated into the SUPs Directive). Avoid PET, paper, PS, PVC, silicone, EVOH, thermoset plastic or metallic caps, liners and seals (WRAP, 2013)
- Lidding film or foil must be totally removable or of the same polymer as the body of the packaging (WRAP, 2013)
- If present, trigger sprays must be made of plastic. As already mentioned, the usage of metals or glass items are not encouraged (WRAP, 2013)
- Avoid or find alternatives (when possible) to absorption pads used into trays since they require glue, posing additional challenges causes for recyclers[115]. At least, try to reduce the amount of glue adopted and select only adhesive removable in water or alkali at 80°C. Tray pads and other shelf life extender (e.g. sheet or strips) must not be made of PET, paper, PVC, EPS, PU, PA, PC, PMMA, thermoset plastics or metals (WRAP, 2013)
- If present, tamper-evident wrap must not be made of materials with a density higher than 1 g/cm^3 (E.g. PVC, PS, PET or metals).

As noticed, questions about the usage of recycled plastics are included to promote the DfromR.
To date, the legislative requirements for a minimum recycled content are established by the SUPs Directive at EU level and the GPP PAN at national level. In the first case, the EC sets a target of 25% of recycled plastic in PET beverage bottles by 2025 and 30% by 2030; in the second case, the MinAmb sets 60% of recycled plastics for primary, secondary, tertiary plastic packaging used in furniture, EEEs, waste containers and 30% in primary reusable packaging used for medical sanitation items[116]. These obligations are reported in the tool. Possible volunteer actions are also investigated to go around the plastic tax.



116 Ministero dell'ambiente – Source: https://www.minambiente.it/pagina/i-criteri-ambientali-minimi

A schematic representation of the **structure** is shown in figure below.

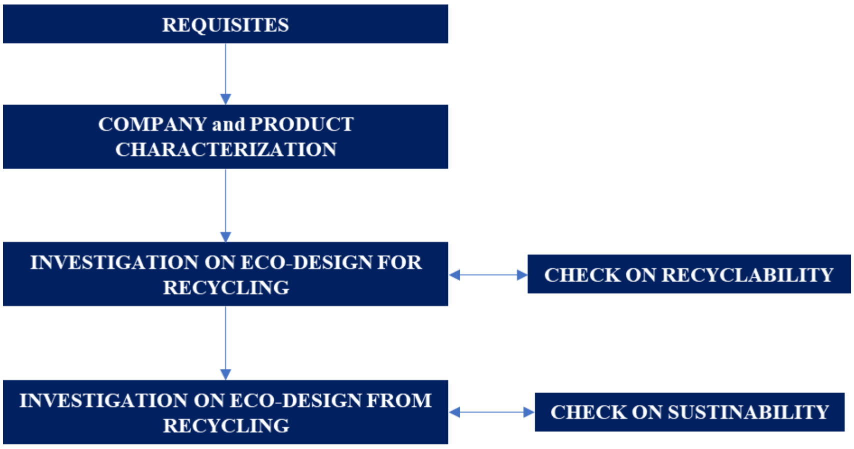


Fig. 112 Schematic representation of the eco-design tool

First of all, a set of requisites have been provided to verify the compliance of the product with the tool. The role of the requisites is to address the analysis to a specific category of products and producers. Then, the list of requisites must be satisfied in totality. Even if just one negative response is present, the study is not appropriate for that hypothetical subject. The requisites are about the identification of the subject that must be a packaging plastic_based and not bio_based because of the problem causing in case of its presence in the conventional mechanical recycling plants.

REQUISITES
Minimum requirements

- **Subject**: plastic packaging finished product, ready to be commercialized
- **Plastic content**: at least 80% in the main body
- **Exclusions**:

- Dangerous and hazardous product;

- Bio-plastics and bio-degradable plastics (E.g. oxo-plastics).

Fig. 113 Requisites for eco-design tool application

CHARACTERIZATION
Company

Company details can be listed as follows:

- Company name
- Location
- Number of plants
- Average turnover[117]
    1. Max 2 mil €
    2. 2 mil € - 10 mil €
    3. 10 mil € - 50 mil €
    4. More than 50 mil €
- Average number of employees:
    1. Max 10
    2. 10 - 50
    3. 50 – 250
    4. More than 250
- Total average number of packaging articles produced per year (including products not intended to be analysed)
- Resources per year (electricity (Kw), water (l), raw materials: polymers, additives (Kg))
- Wastes per year (Kg)
- Packaging volumes ratio[118]: $\frac{n \times V_I}{V_{II}}$, $\frac{n \times V_{II}}{V_{III}}$

Fig. 114 Company characterization

[118] The packaging volumes ratio represents the ability to pack articles at full load and save therefore useless additional packaging material. The *n* stays for number of articles packed, while *V* represents the volume, intended as occupation of S.P.A.ce or capacity according to numerator and denominator respectively. The number obtained will be in the range 0÷1. Nearer will be to 1, higher will be the packaging efficiency.

Tab. 42 Product characterization

CHARACTERIZATION (packaging)	Total packaging	Main body	Primary auxiliary components		Secondary auxiliary components			
			Decorations (labels and sleves)	Closures (caps, liners, seals, lidding film or foil)	Trigger sprays	Tamper-evident wrap	Tray pads, sheet and strips[119]	
	(kg)							Net weight
Plastic component manufactured by the packaging producer		(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	Weighted resin/non resin composition
Plastic component supplied		(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	Weighted resin/non resin composition
Not-plastic component[120]		(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	(kg, %virgin polymers; % recycled polymers)	Weighted material composition

An example of material characterization is given by the beverage bottle showed below.

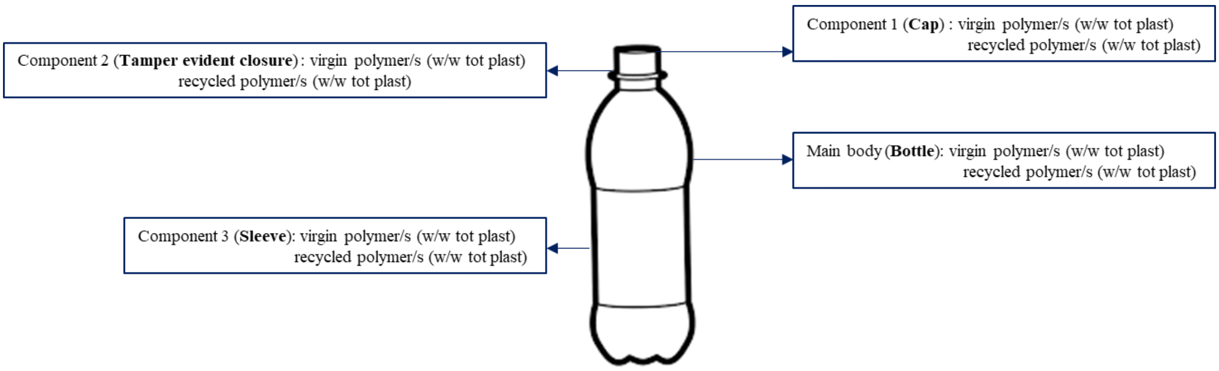


Fig. 115 Material characterization. Plastic bottle example

According to the number of components and their typologies, it is possible to evaluate design aspects.

Tab. 43 Eco-design for design question_based tool

[120] With the term non-plastic components are intended both objects fully made of non-polymeric materials or where plastic is not the main constituent, i.e. less than 50%.

Principle	Question n.1	R	Question n.2	R	Question n.3	R	Question n.4	R	Question n.5	R	Final response on recyclability	Potential CAC
Normative compliance	Is the packaging a cutlery, plate, stirrer or straw?	y									NC	/
Eco-design for recycling (technology)	Is a netted packaging, a capsule, a food EPS_based tray or a tube?	y									NR	C
Simplification principle	Is the packaging composed of only one component?	y	Is the only component of the packaging made of one single polymer?	y	Is a PET, HDPE or PP?	y					R	B1/B2
				n	Is a PE, PP or a polymers (PE/PP) mix compatible with the recycling?	y					R	B1/B2
						n					NR	C
		n	Is the sum of the main body and auxiliary components?	y	Are the components made of plastics?	y	Are the auxiliary components made of the same resin as the main body?	y	Are the auxiliary components (except for sleeves) attached to the main body and not-easily removable?		R	B1
											R	B2
									In case of PET beverage bottle, are lid and cap connected to the main body?		R	B1
											NR	B2
								n	Is a PE, PP or a PE/PP composition?		R	B2
											NR	C
						n	Are glass and metal avoided?	n			NR	C
				n							NR	C
Eco-design for R (colour)	Has the main body got a clear or transparent colour?	y									R	B1/B2
		n	Is the packaging dark, black or opaque ?	y							NR	C
Eco-design for R (Sleeves, prints and inks)	Does the packaging contain a plastic sleeve?	y	Does the sleeve cover the main body (60% in case of bottle and 40% in case of tube, tray etc.)?	y	Has the sleeve the hallmarks for the easly removal (anc contain indication for consumer about its removal)?	y	Is a not-black sleeve made of PE/PP or PE/PP (without glue, metals and paints)?	y			R	B2
								n			R	B1/B2
						n					NR	C
				n	Is the sleeve glued to the main body?	y	Is the adhesive soluble in water or in alkaline solution at 60-80°C?	y			R	B1
								n			NR	C
						n	Has the sleeve the hallmarks for the easly removal (anc contain indication for consumer about its removal)?	y	Is a not-black sleeve made of PE/PP or PE/PP (without glue, metals and paints)?		R	B2
								n			R	B1/B2
		n	Are the information directly printed on the main packaging?	y	Is a water_based ink?	y					R	B1
						n	Is a laser marked?	y			R	B1
								n			NR	C
				n							R	B1
Eco-design for R(Additives)	In case of PET, are bio/oxo/photo/degradants additives or nanocomposites avoided?	y	Is the use of additives alterating the polymer desity (e.g. talc, $CaCO_3$ or gypsium) avoided?	y							R	B1/B2
		n		n							NR	C
	In case of PE and PP, are additives used in concentration<0,97g/cm^3?	y									R	B1/B2
		n									NR	C

Tab. 44 Eco-design from recycling question_based tool

	Question		Question		Question		Question		Question	Legislative requirements	Economic incentives
Design from recycling	In case of PET beverage bottles, does the packaging contain recycled plastics?	y	In case of PET beverage bottles, is the average weight of recycled plastic at least 30% (w/w) of the overall weight of plastic materials?	y	Is the process to manifacture the recycled plastic_based product certified by the EFSA and EC?	y					y
						n					y
				n							y
		n								See SUPs Directive	y
	In case of packaging for forniture sale, does it contain recycled plastics?	y	Is the average total weight of recycled plastic at least 60% (w/w) of the overall primary, secondary or tertiary packaging?	y	Is the product certified by an eco-lebelling (E.g EuCertPlast, PSV, …)	y					y
						n					y
				n							y
		n								See GPP PAN on forniture	n
	In case of packaging for EEEs' sale, does it contain recycled plastics?	y	Is the average total weight of recycled plastic at least 60% (w/w) of the overall primary packaging?	y	Is the product certified by an eco-lebelling (E.g EuCertPlast, PSV, …)	y					y
						n					y
				n							y
		n								See GPP PAN on forniture	n
	In case of packaging for catering, does it contain recycled plastics?	y	Is the average total weight of recycled plastic at least 60% (w/w) of the overall primary, secondary or tertiary packaging?	y	Is the primary packaging in contact with food?	y	Is the process to manifacture the recycled plastic_based product certified by the EFSA and EC?	y	Is the product certified by an eco-lebelling (E.g EuCertPlast, PSV, …)		y
								n			!
				n	Is the product certified by an eco-lebelling (E.g EuCertPlast, PSV, …)					See GPP PAN on catering and restoration	y
		n									n
	In case of reusable packaging for sanitification product, does it contain recycled plastics?	y	Is the average total weight of recycled plastic at least 30% (w/w) of the overall primary reusable packaging?	y	Is the product certified by an eco-lebelling (E.g EuCertPlast, PSV, …)	y					y
						n					y
				n						See GPP PAN on sanification products	n
		n									n

8.3 Circularity: from quantity to quality

8.3.1 Background

The necessity of measuring circularity is recognized as a crucial step to foster the transition. On January 2018, the EC has published the *Communication 29/2018* about the monitoring framework on circular economy where the need of having a set of indicators for monitoring the progresses of CE is highlighted.
Although the research about CE has registered a spike in the last decade, only few studies focus on how to measure effectively the holistic nature of circularity (Crippa et al., 2018). Since CE models can be adopted at different levels (product, supply chain, service etc.) and stages of the value chain (design, production, consumption etc.), a single indicator is not able to reflect all the heterogeneous aspects of circularity. However, a multitude of indicators have been experimented. Few examples are mentioned below:

- the **Material Circularity Index (MCI),** performed by Ellen MacArthur Foundation, is focused on technical cycles and on energy and material flows of non-renewable sources (Ellen Mac Arthur Foundation, 2015).
- the **Circular Economy Toolkit (CET)**, suggested by Evans and Bockens from the University of Cambridge (2017), is an assessment tool developed in 2013 to quantify the circularity performances at a product level, suggesting possible improvement strategies.
- the **Circular Economy Indicator Prototype (CEIP)**, developed by Griffiths and Cayzer (2016), aims to evaluate products' circularity performances too.
- the **Product-Level Circularity Metric**, proposed by Liner et al (2017), is based on the economic value of recirculated parts and components of products.
- the **Circular Material Use Rate**, proposed by EUROSTAT, is calculated as the ratio of the circular use of materials (U) to an indicator of the overall material use (M) (EUROSTAT, 2018)

In the field of plastics, the variety of molecular composition, formulation and application make the challenge more complex. Regarding the plastics recycling, the ability to substitute recycled plastics with virgin plastic resins generally depends on the purity of the recovered plastic feed and the property requirements of the plastic product to be made (Hopewell et al., 2009). Another important aspect is the preservation of the technical value that is necessary to boost the market of secondary materials (Iacovidu et al., 2017). Being a mass recycling index, the existing net recycling yield doesn't give information about the quality of plastics that is one of the greatest challenges of recycling (Hahladakis and Iacovidu, 2018). For the unit of expressing resource efficiency, the scientific literature recommends the use of the economic value (Linder et al., 2017) because most targets in governmental and corporate reports are expressed in terms of economic values. Economic value is extensively used in decision-making (Di Maio et al., 2017). The **Secondary Material Price Indicator** established by the EC considers the average monthly volume of trade in secondary materials and average monthly prices for secondary materials (See Figure 116). It sums up all value and volume of all relevant foreign trade statistics (FTS) codes monitoring both the intra-EU and extra-EU cross-country trade (between MSs and with countries outside of the EU, respectively) but it doesn't enter into detail of the type of plastic resin and waste.

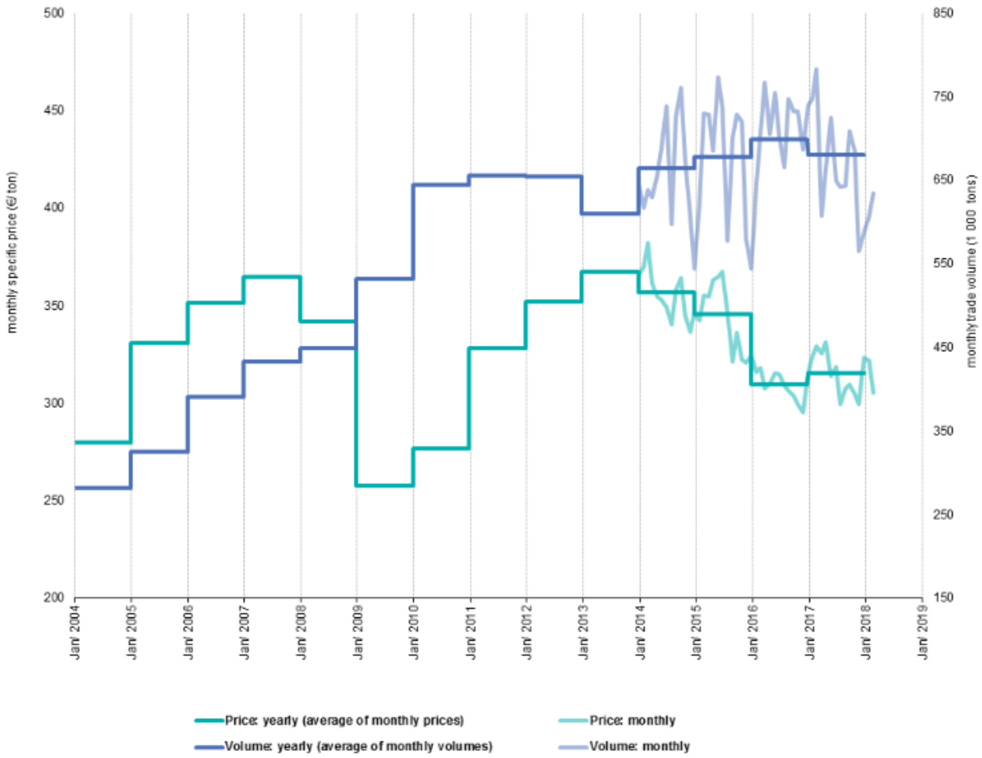


Fig. 116 Secondary Material Price indicator of plastic waste – Source: EUROSTAT

The graph shows how the SPs market is regulated by the price. This makes indicators expressed in economic value better aligned with policies and strategies (Di Maio et al., 2017).

The research activity performed at TU Delft has allowed to experiment the CE indicator (CEI) proposed by Di Maio and Rem (2015) that attempts to fulfill the gap by introducing the economic value of materials as ratio between the material value produced by recyclers and the intrinsic value of material. Subsequently, where mass represents only quantity, economic value (and its considerations at different levels) can represent both quantity and quality. In this way, the indicator gets implicitly information about the quality of SPs in addition to external factors (E.g. Competition with virgin polymer market, Chinese import ban etc.). It seems to be particularly relevant in this transition phase. Calculating the CEI at firm level helps to identify those recyclers that are able to extract more value from the waste streams. The calculation of the CEI over the years will be useful to understand how the regional economy will react to that changes and consequently how efficient are the measures established by the policy makers. Whereas the value_based CEI reflects local situation, it shows more significant information about the context.

8.3.2 Configuration

The following equations show the structure of the CEI based on the value of plastic waste and SPs that flow through the recycling plants.

$$\boldsymbol{CEI} = \frac{Material\ value\ produced\ by\ recyclers}{Material\ value\ entering\ the\ recycling\ facilities} = \frac{Secondary\ plastics\ value\ [\frac{EUR}{t}]}{Plastic\ waste\ \ value\ [\frac{EUR}{t}]}$$

$$\boldsymbol{Secondary\ plastic\ value} = \frac{Turnover\ from\ SPs\ sales\ [EUR]}{Amount\ of\ SPs\ placed\ on\ the\ market\ [t]}$$

$$\boldsymbol{Plastic\ waste\ value} = \frac{Costs\ for\ plastic\ waste\ processing\ [EUR]}{Amount\ of\ plastic\ waste\ processed\ [t]}$$

It follows that:

- **CEI>1** → Turnover from SPs sale is higher than the cost to manufacture the plastic waste → **After use plastic economy**
- **CEI<1** Turnover from SPs sale is lower than the cost to manufacture the plastic waste → **No after use plastic economy**

As shown in the Figure 116, the market grows when prices fall. The prices of SPs dependent on intrinsic factors (E.g. Quality of SPs) as well as external ones (E.g. Price of oil, Price of virgin plastics etc.). The recycling performance optimization positively affects the costs for primary materials, services etc. The cost reductions drive up the entire value of the indicator. A higher ranking pushes the recycling chain to get to have the same quality of virgin materials thus promoting innovation and supporting the replacement of virgin plastics with recycled ones in an after-use plastics economy. The structure of the indicators as well as the information it contains will also support decision makers to correctly direct investments and financial measures.

8.3.3 Application and discussion

As repeatedly stressed, the MFA is not sufficient to provide information about the quality of the SPs out of the recycling plants. On the contrary, it may be misleading: a high recycling yield may communicate high performance of the recycling process; however, in case the commodity consists of mix of recycled plastics rather than PET, unsustainability is deceptively promoted. The indicator here proposed allows to easily move from quantity to quality by associating the value to the mass. In fact, the value here considered is an economic value. The economic value is intended as the turnover resulting from the sale of SPs and the costs for the plastic waste supply. These data are easily found in the financial reporting documents of the economic activities.

Summarizing, data on input-output material stream, costs and prices must be available.

Fig. 117 Input-Output value stream in recycling plants

According to the new method to calculate the recycling target, the input-output material stream will be available when each MB will transpose the Circular Economy Package in national legislation.

At the moment, legislation do not force recyclers to provide data about the total amount of SPs generated every year by the recycling plants, only some have included this information. Moreover, seince the current recycling rate is calculated taking into account all the valorization processes, not only recyclers are considered. As reported in the Table 32, sorting plants are also included.

The following outputs are the results of:

- Recognition of plastic waste recycling plants through analysis of authorizations, identification of the NACE codes, exploration of websites
- Data mining and elaboration from MUD and AIDA dbs and activity B (described in the Chapter 7)
- Design of input-out material and value streams

The following tables shows the regional recycling plants working on the recycling if plastic waste.

As already mentioned in the Chapter 7, the recycling chain is highly fragmentated. Many recycling plants have different value propositions and some of them work on the recycling of different material stream. Only are strictly specialized on the recycling of plastic waste to turn up in SPs.

Tab. 45 List of regional plastic recyclers

REGIONAL PLASTIC RECYCLING PLANTS						
Name	City	Province	Capacity (t)	Authorized treatment	Authorized waste (by EWC)	Market (R=recycler; C=converter)
PETRA POLIMERI S.R.L.	FERRARA	FERRARA	60.000	R3, R13	[19]	R
A.M.P. RECYCLING S.R.L.	FERRARA	FERRARA	20.000	R3, R13	n.a.	R
S.E.R. SRL	PARMA	SALSOMAGGIORE TERME	20.000	R3, R13	n.a.	R
ECOWELL SYSTEM SRL	REGGIO EMILIA	BORETTO	19.200	R3, R13	[07][07][12][19]	R
STARPLASTICK SRL	PARMA	SA	13.470	R3, R13	[07][07][12][16][17][19][20]	R
CHIAPPELLI SRL	MODENA	SAVIGNANO SUL PANARO	10.880	R3, R14	[03[[07][07][12][16][17][19]	R
FORPLAST SRL	PIACENZA	CASTELL'ARQUATO	8.000	R3, R13	[07][07][12]	C
ECOCHIMICA S.R.L.	RAVENNA	LUGO	6.000	R3, R13	[07][07][12]	C
BALBONI OMERO SRL	FERRARA	SANT'AGOSTINO	5.500	R3, R13	[07][07][12][19][20]	R
IN-ECO AMBIENTE SRL	FORLI'-CESENA	FORLI'	5.420	R3, R14	[07][07][12][19]	R
G.M. PLAST DI GIANNI MAGRI	BOLOGNA	ARGELATO	4.400	R3	[02][19]	C
BRAGHIERI PLASTIC S.R.L.	PIACENZA	SARMATO	4.300	R3, R13	[07][07][12][17][19]	R

MIRAPLASTIK S.R.L.	MODENA	MIRANDOLA	4.200	R3, R13	[07][07][12][19]	R
R.O.L. SRL	FORLI'-CESENA	FORLI'	4.000	R3, R13	[07][07][12][20]	C
VAL-PLAST S.R.L	FERRARA	BONDENO	3.400	R3, R13	[07][07][12][19]	C
COMISOL	RAVENNA	FAENZA	2.990	R3, R13	n.a.	P
ME YU MA PLAST SRL	BOLOGNA	MALALBERGO	2.900	R3	[07][07][12][16]	C
NEVICOLOR SPA	LUZZARA	REGGIO EMILIA	2.900	R3, R13	[07][07][12][17]	C
RIMPLASTIC S.R.L.	RAVENNA	CONSELICE	2.760	R3, R13	[07][07][12]	R
F.P. PLAST S.R.L.	REGGIO EMILIA	SCANDIANO	2.464	R3, R13	[07][07]	C
POLAR SRL	FERRARA	FERRARA	2.200	R3, R13	[07][12][16[19]	R
ROSSI ADRIANO DI ROSSI FABRIZIO	FORLI'-CESENA	CESENA	1.200	R3, R13	[12][19]	R
PLASTISAVIO S.P.A.	FORLI'-CESENA	MERCATO SARACENO	1.000	R3, R13	[02][07][07][12][19]	C
B.R. PLAST S.R.L.	FORLI'-CESENA	MERCATO SARACENO	790	R3, R12	[07][07][12][17]	R
N.L.						
POLI LAURA SRL	PARMA	FIDENZA	n.a.	n.a.	n.a.	R
RICCI RECYCLING SRL	FORLI'-CESENA	MERCATO SARACENO	n.a.	n.a.	n.a.	R

The total recycling capacity is 207.974t. 15 recyclers works on plastic packaging valorization. Only 3 are specialized on the valorization of other plastic waste stream. No information are available on six companies.

The CEI has been applied at very micro-level. The experimentation has been done on the four top recyclers[121] working in the region and listed below:

1) **S.E.R. SOCIETA' RIGENERAZIONE EUROPEA S.R.L.**
2) **PETRA POLIMERI S.R.L.**
3) **A.M.P. RECYCLING S.R.L.**
4) **STARPLASTICK S.R.L.**

The following schemes summarize the input-output material stream for the recycling facilities listed above. Data are provided by the companies through the activity B described in the paragraph x.

SER S.R.L. operates on the valorization of household plastic packaging waste to process HDPE. The froup is recently acquired from Sirmax Spa, working on engineering polymers manufacturing for technical applications in automotive and electronic sectors. About the supply chain, the market is Italian with prevalence of Campania and Emilia Romagna. In 2017, the main market was Italian, (with a share of 58%),

[121] No data are available for ECOWELL SYSTEM SRL.

followed by the European (with a market share of 41%) and finally, small amount (1%) of rPET was also sold outside Europe.

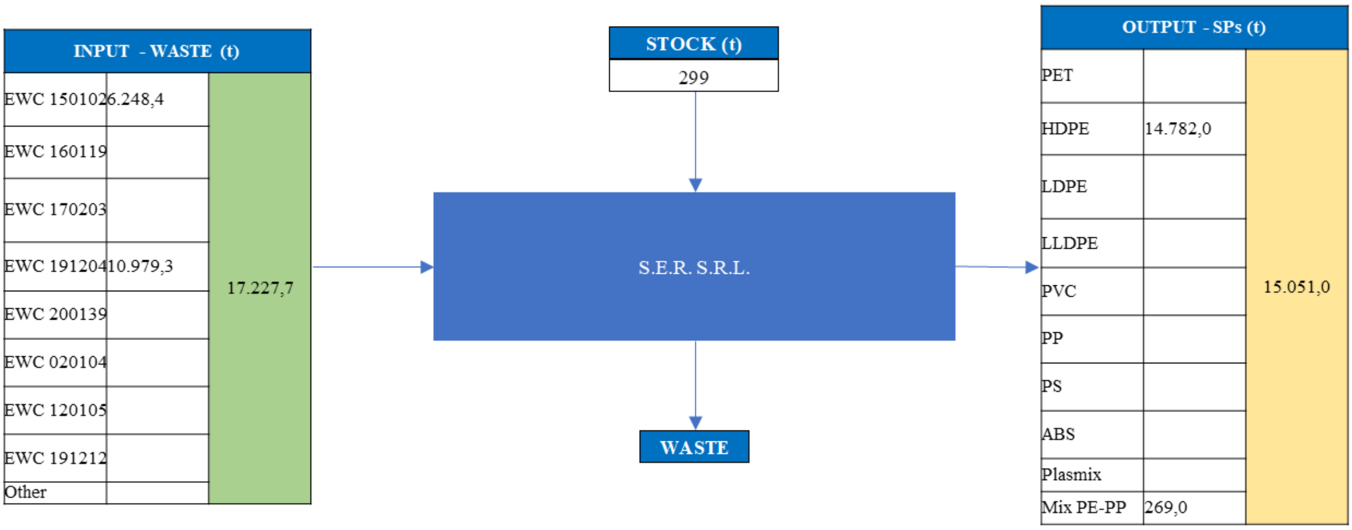


Fig. 118 Input-Output material stream, 2017 - SER S.R.L.

PETRA POLIMERI S.R.L. was founded in 2000 and damaged by an earthquake in 2016. It has been taken over by the ILPA Group S.P.A. to process rPET. This action is strategic for the regional economy where the demand of rPET is high and will continue to grow. In fact, PETRA POLIMERI enters the waste market through the COREPLA system. The supply of plastic waste is mainly Italian with a small share from Europe.

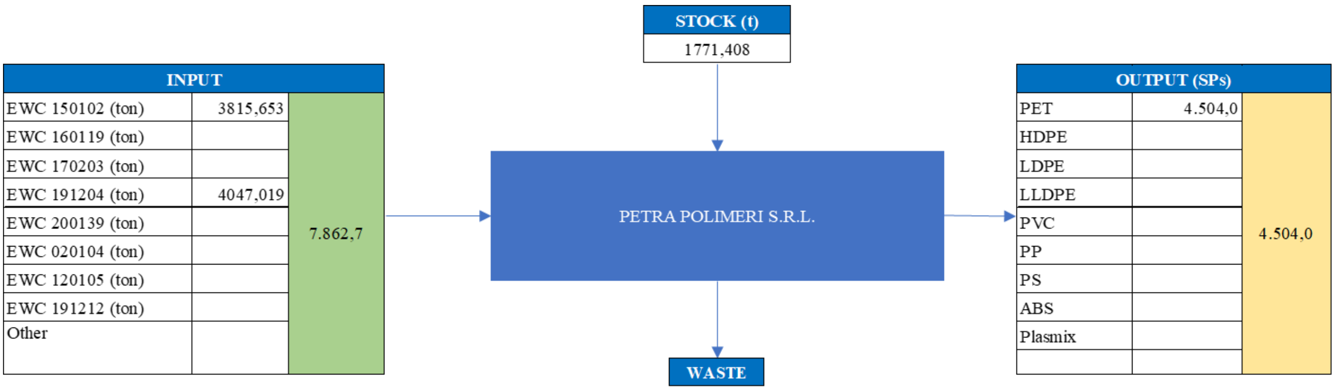


Fig. 119 Input-Output material stream, 2017 – PETRA POLIMERI S.R.L

A.M.P. RECYCLING S.R.L. is part of the ILPA Group S.P.A. The Group consists of MP3 S.R.L. - operating in the supply of finished products and ILIP S.R.L. - working on thermoformed and semi-finished plastic food, AMP Recycling S.R.L., specialized on thermoforming and extrusion processes in one side and PET recycling in another side. With its three divisions (ILIP Srl, AMP Srl and MP3 Srl) ILPA S.P.A. has reinforced its position on a European-wide scale in the segment of thermoformed plastic food packaging, as well as in the segment of semi-finished products for food applications thank to the the implementation of the "Closed loop" system about the re-processing of PET (Foschi and Bonoli, 2019). It follows that the main market of SPs is a regional market. In fact, around 99% of the rPET manufactured in 2017 has been internally managed. Regarding the supply chain, the company participates to the auctions organized by COREPLA. In fact, the legislation establishes that the production of rPET for food-contact applications has been done through the valorization of food packaging waste.

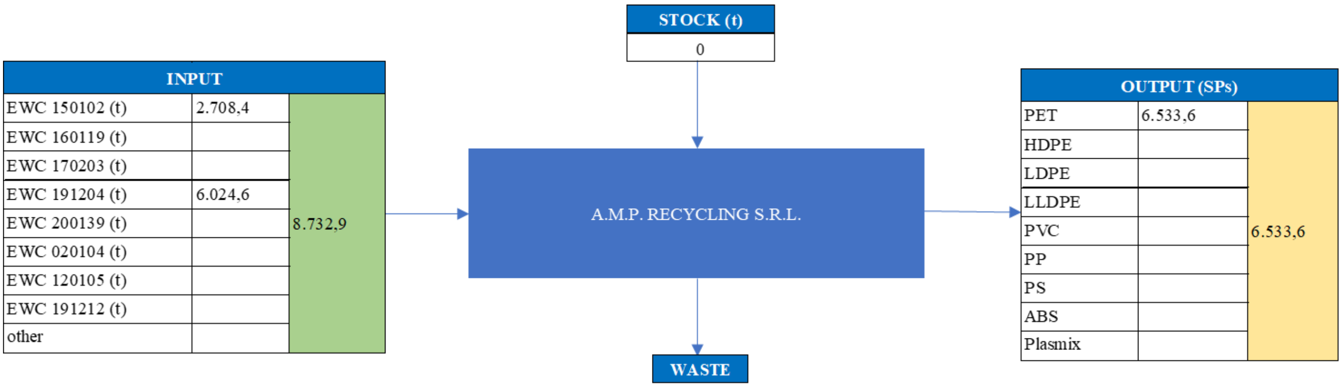


Fig. 120 Input-Output material stream, 2017 – A.M.P. Recycling S.R.L

STARPLASTICK S.R.L. works in sorting and recycling pre and post-consumer plastic waste. It is part of the PIA platform by which the facility valorizes industrial packaging. The MFA shows that the largest amount of the incoming waste comes from the municipal waste stream. STARPLASTICKS work on sorting as well as recycling. The main application of SPs includes garbage bags. In this case, the CEI is calculated for the amount of plastic waste effectively reprocessed in SPs.

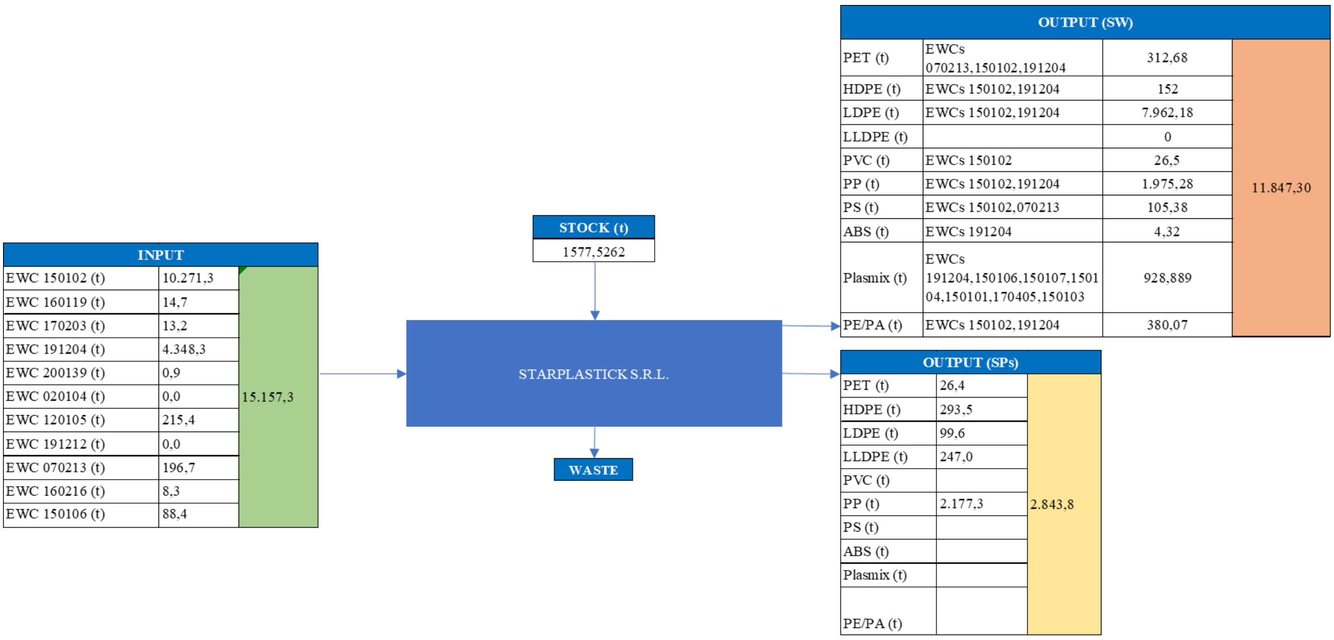


Fig. 121 Input-Output material stream, 2017 – STARPLASTICK S.R.L.

The financial and economic data are extrapolated from the AIDA database that contains the financial statements of over 700.000 Italian economic activities. In particular, the turnover resulting from the purchase and the cost about the raw materials supply and processing are the types of data used to calculate the CEI. The detail of each financial report has allowed to get a better understanding of the business and consequently, to associate the cited turnover to the turnover resulting from the purchase of the SPs. Data extrapolated from the single financial statement have also allowed to identify the dimension of the market. As already described, the main market is local thus facilitating the promotion of the after-use plastic economy in the region.

The following table compare the mass and value based for each recycling company.

Tab. 46 Mass and Value_based recycling yield, 2017 – case studies (*STARPLASTICKS works on sorting as well as recycling)

	Mass_based recycling yield	Value_based recycling yield (CEI)	Market
S.E.R. SOCIETA' RIGENERAZIONE EUROPEA S.R.L.	0,87	1,78	Medical and electic/electronic equipments
PETRA POLIMERI S.R.L.	0,53	2,37	Food packaging
A.M.P. RECYCLING S.R.L.	0,75	1,94	Food packaging
STARPLASTICK S.R.L.	0,2	1,43	Garbage bags*

As already described, the CEI captures the value of plastic materials during the recycling process: the higher the CEI, the higher is the value extracted from waste. It follows that the qualitative assessment can differ from the quantitative one. In this experimentation, the recycling plants managed the same types of waste (EWC 150102 and 190104) in 2017 and produce plastics for different applications. S.E.R. S.R.L. provides solutions in the medical and electric/electronic sectors. A.M.P. RECYCLING S.R.L. and PETRA POLIMERI S.R.L. work to produce food-contact rPET. STARPLASTICKS integrates the waste sorting by polymer type to the recycling, manufacturing garbage bags as well. The results show that PETRA POLIMERI S.R.L. generates the highest value. AMP RECYCLING recycles more than PETRA POLIMERI S.R.L. In case of STARPLASTICKS, the low mass_based value is related to the integration of two business.

8.4 Follow up: the necessity of a real recycling target

According to the *Decision 2011/753/UE*, "*the weight of the waste which is prepared for reuse, recycled or has undergone other material recovery is the amount of waste that is collected separately or the output of a sorting plant that is sent to recycling or other material recovery processes without significant losses.*"

The calculation has been based on four possible methods with different assumptions on total waste meaning:

1) the preparation for reuse and the recycling of paper, metal, plastic and glass household waste[122]
2) the preparation for reuse and the recycling of paper, metal, plastic, glass household waste and other single types of household waste or of similar waste[123] from other origins

[122] Household waste means waste generated by households.
[123] Similar waste means waste in nature and composition comparable to household waste, excluding production waste and waste from agriculture and forestry.

3) the preparation for reuse and the recycling of household waste
4) the preparation for reuse and the recycling of municipal waste[124].

The method 2) and 4) requests the mereological analysis of waste coming from household activities as well as from economic ones (E.g. Restaurants, small enterprises, shops etc.) Details are shown in the table below.

Tab. 47 List of calculation methods for recycling rate. Analysis by country of application – Source: Greenfield and Woodard, 2015

Method	Calculation	Countries[125]
1	*Recycling of paper, metal, plastic and household included in the household waste stream*	Ireland, Malta
2	*Recycling of paper, metal, plastic, glass included in the municipal (household and similar) waste stream*	Austria, Croatia, Cyprus, Czech Republic, Estonia, France, Greece, Hungary, Italy, Lithuania, Poland, Portugal, Romania, Slovakia, Sweden
3	*Recycling of household waste*	Bulgaria, Luxembourg, United Kingdom
4	*Recycling of municipal waste*	Belgium, Denmark, Finland, Germany, Latvia, Netherlands, Slovenia, Spain

It is intuitive that this Decision has created confusion and fragmentation in waste data collection, elaboration and analysis. In fact, MSs have adopted different calculation methods with different interpretations since a legislative definition of sorting process doesn't exist. Some base their calculations on waste collected or sorted, while much of that waste will still be incinerated, landfilled, recycled with low quality processes or exported without guarantee the recycling quality. As highlighted by European Environmental Bureau (EEB), the four methods are not equivalent[126]. In addition, the recycling rate of packaging waste should be calculated as the weight of recycled packaging waste by the weight of total packaging waste. Indeed, it is generally calculated as the weight of the materials leaving the sorting plants or entering the recycling facilities without considering the materials successfully reprocessed (OECD, 2018). According to Eurometaux (European Association of Metals), counting the output of the sorting operation and assume that recycling will take place through further operations is not sufficient because of the underestimation of the amount of losses that are shipped and/or send to landfilling or incineration[127]. These critical issues do not allow to have a clear understanding of the recycling chain. Real recycling will only take place after all sorting operations are completed and where waste fractions are guaranteed to enter a final recycling process where they are reprocessed into substances, materials and products that can be re-inserted into a new application/product. Within the circular economy package, the EC proposed a new definition of **final recycling process** as "*the recycling process which begins when no further mechanical sorting operation is needed and waste materials enter a production process and are effectively reprocessed into products, materials or substances*" following the completion of all necessary sorting. It is different than the **recycling**

[124] Municipal waste means household waste and similar waste. It includes plastics (200139, 150102), metals (200140, 150104, 150111*EWCs), paper and cardboard (200101, 150101 EWCs), glass (200102, 150107 EWCs), bio-waste (200108, 200125, 200201 EWCs), wood (200137*, 200138, 1501 03) as well as WEEE (200121*, 200123*, 200135*, 200136 EWCs) , textiles (200110, 200111, 150109 EWCS), bulky waste (20 03 07EWCs), batteries (200133*, 200134 EWCs) mixed waste (200301, 150106 EWCs) and other (200113*, 200114*, 200115*, 200117*, 200119*, 200126*, 200127*, 200128, 200129*, 200130, 200131*, 200132, 200141, 200199, 200203, 200302, 200303, 200399, 150105, 150110*).
[125] Norway misses.
[126] European Environmental Bureau – Source: http://www.eeb.org/?LinkServID=5398CF3B-5056-B741 DBD7061B02B51F65&showMeta=0&aa.
[127] Eurometaux – Source: https://eurometaux.eu/media/1596/eurometaux-qa-on-recycling-rate-calculation.pdf

definition that was established within the WFD as "*any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations*". It follows that in the new definition, losses of materials which occur before the waste enters the recycling operation (due to other preliminary operations) should not be included in the amount of waste reported as recycled. Those losses can be established on the basis of electronic registries, technical specifications, detailed rules on the calculation of average loss rates for various waste streams or other equivalent measures. The average loss rates should preferably be established at the level of individual sorting facilities and should be linked to the different main types of waste, different sources (such as household or commercial), different collection schemes and different types of sorting processes. However, in case the amount of SPs is considered, it is difficult to obtain reliable data and information about the material processed abroad (European Commission, 2018).
According to the new definition, the EC has established a unique method to calculate the recycling rate that is identified in the method n.4. It has been verified that this new method is much more restrictive that the previous one where the recycling yields was based on the ratio of the amount of plastic waste collected for recycling (excluding the amount rejected at the MRFs) than the amount of plastic waste generated in the same year. The Emilia Romagna Region is not affected by this change because of the inclusion of similar waste in the elaboration, however more effort on the calculation point.
The article 1 of the *Decision 2019/1001* considers the **calculation point** as "*the point where municipal waste materials enter the recycling operation whereby waste is reprocessed into products, materials or substances that are not waste or the point where waste materials cease to be waste as a result of a preparatory operation before being reprocessed*". The article 3 add clarifications considering two alternatives, such as:

- the output of a facility that sends municipal waste for recycling without further preliminary treatment[128]
- the input to a facility where municipal waste enters the recycling operation without further preliminary treatment

where the amount of sorted municipal waste that is rejected by the recycling facility shall not be included in the amount of recycled municipal waste.
MS may use a derogation and measure municipal waste at the output of a sorting operation, provided that further losses due to treatment prior to the recycling operation are deducted and that the output waste is actually recycled.

In case of **recycling rate for municipal plastic packaging**, it is possible to consider:

- Plastic separated by polymers that does not undergo further processing before entering pelletisation, extrusion, or moulding operations
- Plastic flakes that do not undergo further processing before their use in a final product.

[128] If the output of the sorting plant is sent to effective recycling or recovery processes without significant losses, it is acceptable to consider this output to be the weight of the recovered or recycled packaging waste.

The following scheme illustrates the calculation points along the recycling chain.

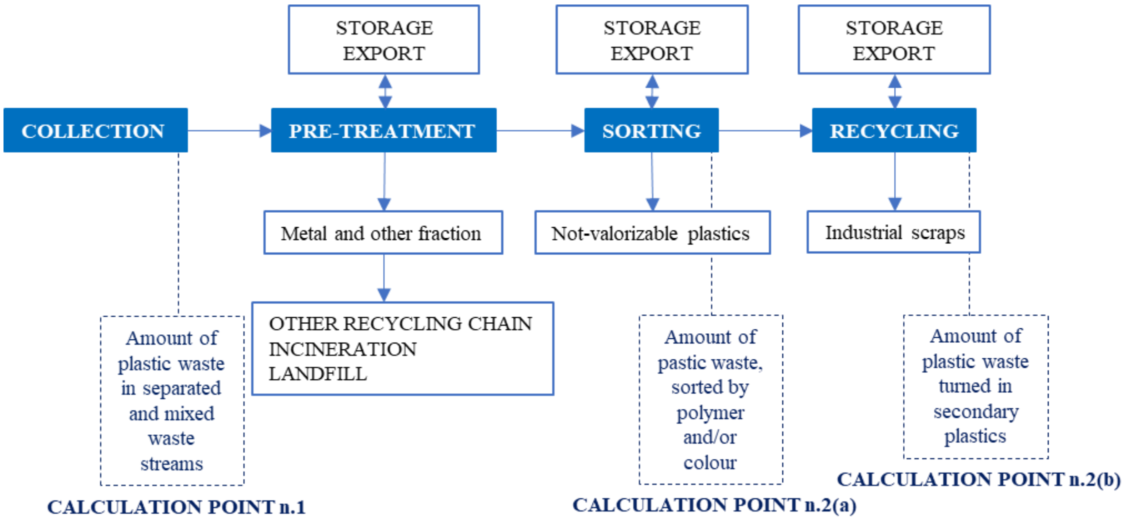


Fig. 122 Overview of calculation points for the plastic packaging recycling yield

The Emilia Romagna Region is actually calculating the recycling rate at the point n.2 (a). Practically speaking, the calculation has been done through the support of the MUD db where the EWCs 200139, 150102 and 191204 are considered. If wastes are exported out of the Union and there is sound evidence that the preparation for reuse, recycling or recovery took place under condition established within the Directive 2008/98/EC, that amount can be considered in the recycling rate calculation. As reported in the Table 32, many MRFs contribute to the regional plastic waste recycling yield. However, it is not representative of the amount of plastic packaging waste effectively reprocessed in SPs. It is necessary to move the calculation point from n.2(a) to n.2(b). As pointed out by Hahladakis et al. (2018). According to what is reported in the document published by the English organization WRAP, efficient MRFs have a 2-5% rejection rate while the less performant plants work rejecting 12-15% of the input materials (WRAP, 2006). The Italian analysis performed by Ecocerved reports an 80% recycling yield. It means that additional 20% of valorized plastics are lost during the final reprocessing step (Fondazione per lo sviluppo sostenibile, 2019).
A mandatory legislative requirement aimed to monitor the generation of SPs doesn’t exist at the moment. Since the effective generation of SPs is still underperforming in Europe as well as in the region, establishing a real recycling yield is actually challenging. However, the CEI may support the recyclers to improve their performances in the transition phase.

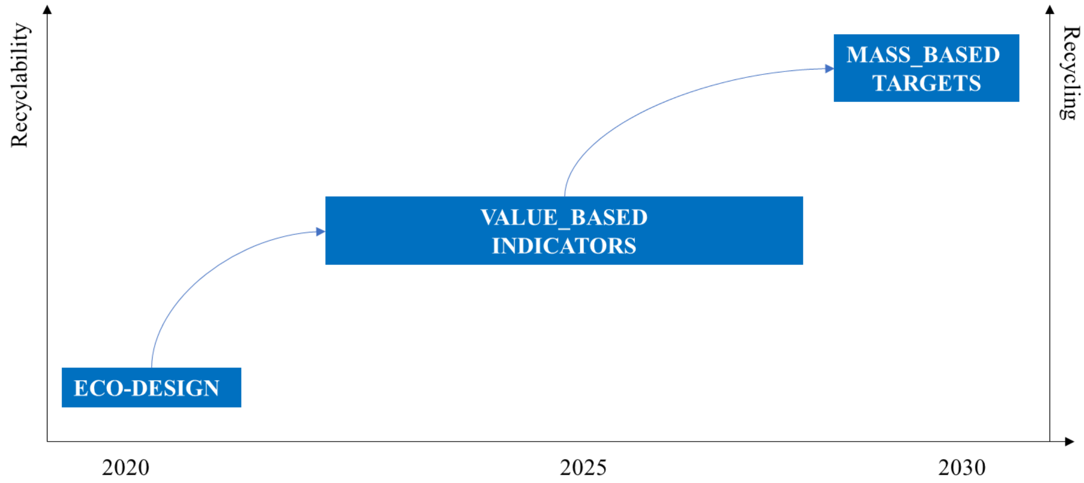


Fig. 123 Circularity Strategy, roadmap

Summarizing, the eco-design tool is the first element to use. DforR and DfromR will supports the plastic packaging manufacturers to improve the recycling performance at the EoL. At the same time, the structure of the tool (organized as a check list) will support the identification of recyclable packaging. Both the activities will contribute to reach the recyclability target. However, eco-design is not enough. The recycling chain should be deeply analysed in order to assess the how much value the recyclers are able to extract from waste. The monitoring of the value_based indicators will speed up the market of SPs in the direction of high value applications, thus effectively contributing to the reduce the virgin plastics supply. This action will foster the achievement of the recycling target. Finally, when a well-functioning market is established, the definition of a recycling yield, based on the effective generation of SPs, will additionally support the trend and therefore, the establishment of an after-use plastics economy.

9 CONCLUSION

Plastic materials have been largely used over the last decades registering a fourfold increase since 1960 (Jambeck et al., 2015). Their versatile nature, durability and lightness have positively affected some sectors such as the packaging and the automotive ones. The penetration of plastic packaging in daily life and plastic components in vehicles have turned up a sensible reduction of atmospheric emissions during the distribution of goods and a food waste minimization during the consumption stage. However, plastics is actually overconsumed. Overpackaging is a large problem. Moreover, the current lifestyle, and in particular the on-the-go trend, (and consequently the growing number of FMCGs) have massively contributed to spike the plastics demand. However, at the increasing plastic consumption, a greater awareness and responsiveness from users and consumers has not be paid. The perception about the low value of some plastic goods at the usage stage has led to mismanage that material at such a point that the MPP is one of the most urgent problem to deal with nowadays. Many initiatives have been established to reduce the environmental impact in the last years. The *Circular Plastic Alliance* (fostering a well-functioning market of recycled plastics), the *Alliance to End of Plastic Waste* (looking for solutions to minimize and manage plastic waste), the *Fair Plastic Alliance* (supporting the developing countries in boosting an after-use plastics economy) and many joint-ventures, cross-cutting collaborations have been recently widespread (Foschi and Bonoli, 2019). In this landscape, the major contribution has been provided by the EC by publishing the first EU-wide policy framework adopting a material-specific lifecycle approach. The ***European Green Deal*** as well as the ***European Strategy for plastics in a circular*** *economy* (that is part of the ***Circular Economy action plan)*** include very full and ambitious programmes to rethink the entire plastic value chain. The mission of the Commission is to highlight the intrinsic value of materials along the value chain and in further cycles. The penetration of digitalization in plastics fields has boosted the creation of added value as well. Sharing service is the symbol of this new way of making business. It means moving from product to service by dematerializing goods and sharing the value of that goods. Product-service system is one of the business models supporting prevention in accordance to the hierarchy of waste pointed out by the EC within the WFD. However, it is not always possible. For those products that cannot be dematerialized, recycling, an in particular **upcycling,** represents a valid alternative. It is well-know that fossil-based plastics cause huge environmental impact across the entire value chain, from the supply of resources to the disposal of the final goods. However, closing the loop allows to allocate that impact in further cycles. It is difficult to turn into fact that principle nowadays: the variety in the chemical composition of plastic polymers, the complex design, the multitude of applications, the presence of contamination, the legislative barriers as well as the competition with the virgin plastics are only some of the bottleneck that challenge the recycling process, further contributing to the pollution problem (Barra and Gonzalez, 2018). As highlighted by the World Economic Forum and Ellen MacArthur Foundation (2017), a New Plastic Economy is necessary. The so-called after-use plastic economy is based on the idea that plastics never become waste; rather, they return to the economy as precious technical or biological nutrients. In effect, the new plastics economy is aligned with the principles of the circular economy and the ambition to provide better economic and environmental results, drastically reducing the loss of plastics in natural systems (especially the ocean) and decouple from fossil raw materials (Paletta et al., 2019). There are some possible solutions. For instance, in order to realize the circular economy of plastics, it is necessary to rethink the design of plastic products and processes, making them fully recyclable. A monitoring of mass and value at EoL permits to push the market of SPs in high-value applications. In order to do that, the EoL has to be considered during the design stage, therefore LCT become crucial. Moreover, it requires the knowledge of the local infrastructure and governance. An integrated and transversal view of the global value chains of plastics must be envisioned. It means adopting **system innovation** that encompasses technological or social innovation by penetrating the system in all the economic, social, political, organizational aspects. Since system innovation brings about a fundamental and

radical change in the way societal functions are performed, systemic thinking support to redesign the plastic goods (packaging in this case) reflecting not only the technical performance but also the system in which the good works. System innovation and **life cycle thinking** are the basic principles of this work.

Nevertheless, even if the plastic strategy is European, the context specifications help to be more pragmatic. Since each EU MS has to transpose the European Directives in two years, working locally helps policy makers to plan an effective political agenda. As system innovation laid down on transition engineering, the transition theory defines the niche as the smallest space of experimentation. In this work, the niche has been represented by the ERR that is the case study of the present work. The region has been seen as space in which search for something able to speed up the after-use plastic economy. It takes on greater importance in Emilia Romagna where the ***Packaging valley*** is located. Therefore, regional packaging value chain must assume a leadership to go beyond small-scale and incremental improvements, and towards achieving a systemic shift to plastics as part of the CE. The ability of companies to create innovation in raw materials, products, packaging, and production and distribution processes is essential. From the management point of view, a new paradigm with the environment must be considered: sustainability must be integrated in the firm rather than be considered as an externality (Aras and Crowther, 2009). Moreover, companies cannot operate as isolated organizational silos; they need more collaboration with all the stakeholders involved in the co-production of a complex outcome such as the reduction of environmental pollution. This concerns the greater integration in BtoB relations, between brands, manufacturers of plastic resins and packaging and finally, companies involved in the collection, sorting and reprocessing operations. This issue is emphasised in the conversion industry, where SMEs are the majority. The long and profitable collaboration with the Region has led to deeply analyse the entire framework and search for solutions. The ***Circularity Strategy*** has been set up. It is the result of the backcasting participative process by which the stakeholders have been involved to highlight challenges, bottlenecks and needs in one side and orientate the problem and define the strategy to achieve the desirable future in another. Backcasting method can be considered a preliminary activity supporting the identification of the gap between the present and the desirable future. Taking up the commitment of the EC, the desirable future has been envisioned through the objectives established for the year 2030 that are summarized in **100% recyclability and 55% recycling of plastic packaging**. According to that objectives, 10 Mt of plastics (accounting for 200% of the current volume circulating in Europe) must be valorized in Europe. About 92.000 t must be indeed valorized in the region. Furthermore, the various commitments established by the packaging industry have also ensured 5-7,5Mt (200-300%) of plastic waste to turn into new resource.

The implications of this work are multiple. Firstly, it is clear that high recycling targets and a well-working SPs market cannot be pursued only by industry. An important node of this CE network is represented by both the municipal and regional administrations, which control the post-use infrastructure and are often the centre of innovation. Secondly, no less important is the role of decision makers in creating the institutional conditions that promote the transition to the plastics CE, realigning economic incentives to businesses, cities and citizens, facilitating secondary markets, setting standards and stimulating innovation (Paletta et al., 2019). In a so complex system, where a multitude of stakeholders operate, a strong work has been done to map everybody. The **Net Map** has allowed to connect stakeholders with the objective. Then, stakeholders have been analysed through the **Relevance-Interest matrix**. The matrix has collected stakeholders and identified those may have an active role in the achievement of the goals. The identification of primary, secondary, tertiary stakeholders has led to find those may better contribute to the final goals. Designers, manufacturers of packaging materials and packaging machinery as well as households, industrial or commercial users but also waste operators and policy and decision-makers are the main stakeholders involved in the plastic packaging value chain. That **primary stakeholders**, called actors, can be direct or facilitating stakeholders. Facilitating stakeholders are categorized as stakeholders who provide the instruments to achieve the final goals. The facilitating stakeholders identified in the region have been the DG ENV and DG ECO of the region itself and ARPAE. Since the system is an open system, additional

facilitating stakeholders have been found thus including ISPRA, ANCI, COREPLA/CONAI as national facilitating stakeholders and DG ENV of EC, PRE, PlasticsEurope and EXPRA as European ones. The exclusion of some stakeholders has been motivated by the fact that plastic packaging has a structured governance, both financial and economic. Regarding the direct stakeholders, packaging producers, recyclers and disposers are investigated. The link between the two stages is represented by the EPR that is practiced by financial instruments like the packaging tax. However, as opposed to the plastic packaging industry (that accounted for 90 companies in 2017), the WMS proves to be really complex: national, independent consortia and single facilities co-operate in the same environment. COREPLA (the national plastic packaging waste consortium) has operated for years in a sort of monopoly. The creation of PARI, CONIP and CORIPET consortia has led to an increasing competition in the economy of waste. The current challenge is manly represented by the co-existence of COREPLA and CORIPET that work in the same segment concerning the municipal plastic packaging. However, COREPLA has a well-defined structure characterized by pre-sorting (CCs), sorting (CSSs) and recycling plants. In the region 14 CCs, 3 CSSs are located. Moreover, some platforms can also operate in the industrial packaging segment: 7 regional plants are associated to the PIA platform and manage general plastic packaging, 4 work PS packaging within the PEPS platform and only one is part of the PIFU platform operating the valorisation of drums and tanks. In general, about 110 MRFs are in the Region: 52 facilities operate in accordance to the R3 recycling code and 42 pants work in accordance to the recycling code R12; 3 recover metals from waste and 11 recover other materials. The SA has been accompanied by the MFA. Approximately, 279.818t of plastic packaging were produced in the region in 2017. In the same year, 132.773t were disposed of in separated collection scheme while 147.045t where collected in mixed waste bins. It is a serious problem because of the second stream is generally sent to MBT, WtE plants or landfilling. The region should invest in **awareness-raising activity**. Of 132.773t, around 91% were household plastic packaging waste. 96.771t were managed by COREPLA registering about 49.299t of plastic waste sorted by polymers and colour and sold through electronic auctions in the EU market. Regarding the overall plastic waste managed in the region, 76% was sent to material and energy recovery (respect to the plastic waste separately collected) but only 22% (calculated as ratio of recycled plastics and the total plastic waste collected, including assimilated/similar waste and the waste collected in mixed waste stream) was effectively recycled. The quantitative analysis has pointed out that recycling is not so efficient in the region. The recycling chain is strongly fragmentated and the majority works on the pre-treatment processes. Only few companies operate the reprocessing of waste in new resources. Moreover, the recycling rate (better defined as the preparing for recycling rate) is not representative of the real recycling performance. Major efforts are necessary to achieve the new recycling targets. The understanding of the gap between the present and the future has led to identify the barriers hindering the recycling. The **barriers analysis** has been conducted embracing three levels of study (micro, meso and macro) and six criteria (political, economic, social, technical/technological, environmental and legal). Depending on the level of implementation of the process, it has been performed by using different approaches and tools (survey, questionnaires and semi-structured interviews). The barriers highlighted by converters, recyclers, policy makers and the above-mentioned organizations have pointed out the necessity to coordinate problems and needs. The difficulties met by recyclers to sort complex goods, the lack of data able to track the entire material streams, the presence of differences in financial and organizational structure of compliance schemes, the aggravating factors regarding an unclear and fragmentated legislation, are some of the bottlenecks contributing to the inefficiency of the regional WMS. The results coming from the qualitative analysis have been confirmed by the qualitative ones: the wide variety plastic-based applications reflect the presence in the waste stream composition as evidenced by the big generation of mixed and contaminated plastics. Even if industrial waste are affected by more evenness, the public-private governance and the increasing number in waste consortia and platforms contribute to fragment the waste streams traceability and therefore the monitoring of the regional capacity. Finally, the status of SPs, that are no longer waste, doesn't allow the traceability by official data collection scheme. It follows that the lack of technological, logistic, economic and environmental data, in an aggregated and harmonized form, gets difficult insight to provide a clear picture on recycling, both for municipal and special waste. A rethinking of data collection and elaboration should be carried out in order to provide a clear EoL picture of plastic goods. The study has underlined the following recommendations:

- Promote all type of actions fostering the **reduction of plastic waste**.
- Raise awareness of consumers in order to avoid the PCPPW disposal in the commingled collection
- **Implement the DPR**, especially for PET bottles with the aim to reduce the contamination in one hand and maximize the profitability of rPET market in another.
- **Promote eco-design** through training activities and financial measures thus supporting the reduction of mixed and contaminated plastic waste that represents the main cost and environmental impact of the waste management.
- **Harmonize data collection** among national and independent consortia.
- Initiate **focus groups** discussing the introduction of actions aimed to monitor the flow through of SPs at first and the implementation of industrial synergies then.
- **Support remanufacturers to produce recognizable high-quality SPs** and monitor the performance through value-based metrics.
- **Invest on new industrial recycling infrastructure** ensuring the fulfilment of the regional demand and the application of the proximity principle (as established by the article 182bis of the Legislative Decree 152/06).

At the same time, the best practices and the virtuous companies operating the CE have been analysed. As result, most of the manufacturers internally recycle scraps. Others use recycled plastics for a multitude of applications (included high value applications) but with a low proportion respect to the use of virgin plastics. The match-making workshop has figured out a multidisciplinary space of discussion where the main contribution has been offered by the industrial stakeholders who voiced the need to have clear legislation and robust financial support to switch the production towards more sustainable patterns. The **inside of outside analysis,** supported by the **context map**, has oriented the problem: a greater integration of recycling activities into the plastics value chain is essential and may be facilitated by the cross-cutting collaboration between plastics designers, manufacturers and recyclers The lack of expertise on CE has also highlighted the need to have something able to assess the sustainability of new products, processes and supply chain. The **gaps analysis** has entailed a matchmaking between industry commitments and policy interventions in three fundamental steps, such as **design, recycling** and in particular, upcycling. These key points are the pillars of the Circularity Strategy whom action plan regards the establishment of an eco-design (for and from recycling) tool and the calculation of the recycling performance from the mass and value point of views. The three elements have been figured out and explored to validate their functionality and potentiality. The applications of the eco-design (for recycling) tools fosters the packaging design in accordance to the category established by the COREPLA regarding the eco-modulation fee for packaging tax. The eco-design from recycling doesn’t include technical requirements but communicate the possible legislative requirements and economic incentives or taxes affecting the product manufacturing. Many plastics converters were taken down about the possible measures that may incentivize the conversion of their business. As the region mainly hosts SMEs, the tool can be considered a training apparatus that stimulate the stakeholders through incentives that have been identified in the modulation of the CAC, VAT discount and plastic tax. While the first part of the apparatus aims to fulfil the product_level goal and therefore allocate the responsibility at the first stages of the value chain, the second element, represented by a value_based indicator measuring the performance of recyclers, is more useful for policy and decision makers as well as organizations like COREPLA, ANCI ARPAE. The measurement of the effective recycling yield has pointed out the necessity to reduce waste at first, increase the quality of collection then and deal with the problem of plasmix. The calculation of the CEI allows to understand the performance of the regional recycling. Even if the case studies are performed in an explorative way, the results confirm that an higher recycling yield is not necessarily accompanied by an higher economic value. It becomes extremely important to foster regional recyclers to improve the quality of SPs. According to the action plan, one the eco-design will be implemented, the CEI will guarantee the generation of more value from waste. Then, real recycling yield based on the amount of SPs generated will easily fit the EU targets. It requires additional data such as the knowledge about the amount of SPs generated by each MRF. Therefore, data should be shared by the recyclers. This is possible if legislation supports this activity.

Summarizing, this work has set the basis and the instruments to establish the Circularity Strategy aimed to turn about 92.000t of plastic waste into profitable secondary resources. A deep understanding of the present situation has led to identify the challenges. The Circularity Strategy, based on recyclability and high-value recycling of plastic packaging and plastic packaging waste, will be presented to the ERR that is working on the so-called *#PlasticFreER* strategy in one side and on the *2021-2027 Cohesion policy* in another. The model at the basis of the Circularity strategy may also be exported in other EU countries thus promoting standardization in design, harmonization in the assessment of recycling performance as well as the introduction of a reliable and robust indicator considering the value by which increase competitiveness and foster the after-use plastics economy in local economy thus reducing export, illegal trade and arson. Part of this actions are already operative thanks to the support of KIDV.

REFERENCE

─ Executive summary

Andrady, A. L. (2003). Plastics and the Marine Environment. In *Plastics and the Environment*.

Berkhout, F. (2002). Technological regimes, path dependency and the environment. *Global Environmental Change*, 12(1), 1-4.

Brooks, A. L., Wang, S., & Jambeck, J. R. (2018). The Chinese import ban and its impact on global plastic waste trade. *Science Advances*. https://doi.org/10.1126/sciadv.aat0131.

Browne, M. A., Galloway, T., & Thompson, R. (2007). Microplastic--an emerging contaminant of potential concern? *Integrated Environmental Assessment and Management*. https://doi.org/10.1897/1551-3793(2007)3[559:LD]2.0.CO;2

Crippa, M., De Wilde, B., Koopmans, R., Leyssens, J., Muncke, J., Ritschkoff A-C., Van Doorsselaer, K., Velis, C. & Wagner, M. A (2019). Circular economy for plastics – Insights from research and innovation to inform policy and funding decisions, European Commission, Brussels, Belgium.

Eagle, L., Hamann, M., and Low, D.R. (2016). The role of social marketing, marine turtles and sustainable tourism in reducing plastic pollution. *Marine Pollution Bulletin*, 107 (1), 324-332.

Ellen MacArthur Foundation. (2016). The New Plastics Economy: Rethinking the future of plastics. Ellen MacArthur Foundation. Available online: https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics

Regione Emilia Romagna (2019). Strategia Regionale Per La Riduzione Dell'incidenza Delle Plastiche Sull'ambiente. Available online: http://servizissiir.regione.emilia-romagna.it/deliberegiunta/servlet/AdapterHTTP?action_name=ACTIONRICERCADELIBERE&operation=leggi&cod_protocollo=GPG/2019/1205&ENTE=1

European Commission (2015). An EU Action Plan for the Circular Economy. COM (2015) 614. Available online: https://doi.org/10.1017/CBO9781107415324.004

European Commission (2018). Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. A European Strategy for Plastics in a Circular Economy. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN

European Commission (2019a). Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions. *The European Green Deal*. Available online: https://ec.europa.eu/info/publications/communication-european-green-deal_en

European Commission (2019b). A Circular Economy for Plastics. Insights from research and innovation to inform policy and funding decisions. Available online: https://op.europa.eu/en/publication-detail/-/publication/33251cf9-3b0b-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-87705298

European Environmental Agency (2017). Circular by design. Products in the circular economy. ISBN 978-92-9213-857-8 ISSN 1977-8449 doi:10.2800/860754

European Parliament and the Council of the European Union (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal of the European Union. https://doi.org/2008/98/EC.; 32008L0098

Foschi, E., Bonoli. A. (2019). The Commitment of Packaging Industry in the Framework of the European Strategy for Plastics in a Circular Economy. *Administrative Science Journal*. doi:10.3390/admsci9010018

Gallimore, A., Cheung, W.M. (2015). Effects of environmental impact based on alternative materials and process selection in automotive component design. *Journal of Industrial and Production Engineering.* https://doi.org/10.1080/21681015.2016.1172123

Geels, F. W. (2006). System innovations and transitions to sustainability: challenges for innovation theory. In Proceedings of SPRU 40th Anniversary Conference,11-13 September 2006.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production.* https://doi.org/10.1016/j.jclepro.2016.12.048

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*. https://doi.org/10.1126/sciadv.1700782

Gregory, M. R. (1991). The hazards of persistent marine pollution: Drift plastics and conservation islands. *Journal of the Royal Society of New Zealand*. https://doi.org/10.1080/03036758.1991.10431398

Hagedoorn, J. (2002). Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Research Policy*, 31: 477–92.

Hagemeier-Klose, M., Beichler, S. A., Davidse, B. J., & Deppisch, S. (2014). The Dynamic Knowledge Loop: Inter- and Transdisciplinary Cooperation and Adaptation of Climate Change Knowledge. *International Journal of Disaster Risk Science*. https://doi.org/10.1007/s13753-014-0015-4

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2008.0311

Imogen, E., Napper, Thompson, R. C. (2019). Marine Plastic Pollution: Other than microplastic. *Waste, a handbook for management.* https://doi.org/10.1016/B978-0-12-815060-3.00022-0

Jackson T. (2005). Sustainable Consumption. *Handbook of sustainable development*. E-SBN 978 1 78254 470 8.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … Law, K. L. (2015). *The ocean. Science*, 347, 768–771. *Science*. https://doi.org/10.1126/science.1260352

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347 (2015), 768-771.

Karlsson, T.M., Arneborg, L., Broström, G., Almroth, B.C., Gipperth, L., and Hassellöv, M. (2018). The unaccountability case of plastic pellet pollution. *Marine Pollution Bulletin*, 129(1), 52-60.

Kemp, R., Rotmans, J. (2005). The Management of the Co-evolution of Technical, Environmental and Social Systems, in: Weber, M., Hemmelskamp, J. (Eds.), Towards environmental innovation systems. Berlin, New York: Springer, pp. 33-55.

Kwon, B.G., Chung, S.Y., Park, S.S., and Saido, K. (2018). Qualitative assessment to determine internal and external factors influencing the origin of styrene oligomers pollution by polystyrene plastic in coastal marine environments. *Environmental Pollution*, 234, 167-173.

Landon-Lane, M. (2018). Corporate social responsibility in marine plastic debris governance. *Marine Pollution Bulletin*, 127, 310-319. https://doi.org/10.1016/j.marpolbul.2017.11.054

Le Blevennec K., Jepsen D., Rödig L., Vanderreydt J., Wirth O. (2019). For Better Not Worse: Applying Ecod-esign Principles To Plastics in The Circular Economy. Available online: https://ecostandard.org/wp-content/uploads/2019/06/APPLYING-ECODESIGN-PRINCIPLES-TO-PLASTICS.pdf

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, 5:6. https://doi.org/10.1057/s41599-018-0212-7

Liu, J. H., & Sibley, C. G. (2004). Attitudes and behavior in social Space: Public good interventions based on shared representations and environmental influences. *Journal of Environmental Psychology*. https://doi.org/10.1016/j.jenvp.2003.12.003

Lusher, A., Hollman, P., & Mandoza-Hill, J. . J. (2017). Microplastics in fisheries and aquaculture. *FAO Fisheries and Aquaculture Technical Paper*. https://doi.org/dmd.105.006999 [pii]\r10.1124/dmd.105.006999

Metcalfe, J. Stan, and Rod W. Coombs. (2000). Organizing for Innovation: Co-Ordinating Distributed Innovation Capabilities. In *Competence, Governance and Entrepreurship*. Oxford: Oxford University Press.

Napper, I.E., Bakir, A., Rowland, S.J., and Thompson, R.C. (2015). Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. *Mar. Pollut. Bull*., 99 (1–2), 178-185.

OECD (2018). Business Models for the Circular Economy: Opportunities and Challenges from a Policy Perspective, OECD Publishing, Paris. Available online: https://www.oecd.org/environment/waste/policy-highlights-business-models-for-the-circular-economy.pdf

Passafaro, P., Maricchiolo, F., Angelici, A., Ciaraldi, V., Giannetti, S., Ludovici, S., … Rosana, S. (2015). A beliefs-based measure of attitudes towards urban littering. *BPA Applied Psychology Bulletin*.

PlasticsEurope (2010). Plastics - the facts 2010. An analysis of European plastics production, demand and recovery for 2009. Available online: https://www.plasticseurope.org/en/resources/publications/171-plastics-facts-2010

PlasticsEurope (2018). Plastics – the facts 2018. Available online: https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

PlasticsEurope (2019). Plastics – the facts 2019. Available online: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

Pruter, A. T. (1987). Sources, quantities and distribution of persistent plastics in the marine environment. *Marine Pollution Bulletin*. https://doi.org/10.1016/S0025-326X(87)80016-4.

Quist, J. (2016). Backcasting. In *Foresight in Organizations: Methods and Tools*. https://doi.org/10.4324/9781315728513

Quist, J., & Vergragt, P. (2006). Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. *Futures*. https://doi.org/10.1016/j.futures.2006.02.010

Sartorius, C. (2006). Second-order sustainability–conditions for the development of sustainable innovations in a dynamic environment. *Ecological Economics,* 58(2), 268-286.

Stefatos, A., Charalampakis, M., Papatheodorou, G., & Ferentinos, G. (1999). Marine debris on the seafloor of the Mediterranean Sea: Examples from two enclosed gulfs in western Greece. *Marine Pollution Bulletin*. https://doi.org/10.1016/S0025-326X(98)00141-6

ten Brink, Patrick et al. (2018). Circular economy measures to keep plastics and their value in the economy, avoid waste and reduce marine litter, *Economics Discussion Papers*, No. 2018-3, Kiel Institute for the World Economy (IfW), Kiel.

Thabrew, L., Wiek, A., & Ries, R. (2009). Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2008.03.008

UNEP (2105). Sustainable Consumption and Production: A Handbook for Policymakers. United Nations Environment Programme. https://doi.org/10.13140/2.1.4203.8569

Velis, C. A., & Brunner, P. H. (2013). Recycling and resource efficiency: It is time for a change from quantity to quality. *Waste Management and Research*. https://doi.org/10.1177/0734242X13489782

Vieira PF. (1992). Environmental problematic and social sciences in Brazil. Ecology and development: problematic and politics, Rio de Janeiro: *Escola Profissional para a Educac¸a˜o e* Desenvolvimento (EPED).

Villanueva, A., Eder, P. (2014). End-of-Waste criteria for waste plastic for conversion. Available online: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/end-waste-criteria-waste-plastic-conversion-technical-proposals

Wang, J., Tan, Z., Peng, J., Qiu, Q., and Li, M. (2016). The behaviours of microplastics in the marine environment. *Mar. Environ.* Res., 113, 7-17. https://doi.org/10.1016/j.marenvres.2015.10.014

WCED (1987). Our Common Future (The Brundtland Report). *Medicine and War*. https://doi.org/10.1080/07488008808408783

Wilber, R.J. (1987). Plastic in the North Atlantic. *Oceanus* 30, 61–68.

WPO (2008). Market Statistics and Future Trends in Global Packaging. *Journal of Chemical Information and Modeling*. https://doi.org/10.1017/CBO9781107415324.004

Yuan Z., Moriguichi Bi. J. (2008). The circular economy: a new development Strategy in China. *J. Ind. Ecol.*, 10, pp. 4-8.

– Chapter 1

Asheim, B. T., & Gertler, M. S. (2009). The Geography of Innovation: Regional Innovation Systems. In *The Oxford Handbook of Innovation*. https://doi.org/10.1093/oxfordhb/9780199286805.003.0011

Bentivogli, C., Quintiliani, F., Mirenda, L., Panicara, E., Manzoli E., Madau, M. (2018). Economie regionali. L'economia dell'Emilia-Romagna.

Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. *Futures*. https://doi.org/10.1016/j.futures.2005.12.002

Dreborg, K. H. (1996). Essence of backcasting. *Futures*. https://doi.org/10.1016/S0016-3287(96)00044-4

Edquist, C. (2011). Design of innovation policy through diagnostic analysis: Identification of systemic problems (or failures). *Industrial and Corporate Change*. https://doi.org/10.1093/icc/dtr060

European Commission. (2019c). Regional Innovation Scoreboard 2019. Available online: file:///C:/Users/utente/Downloads/Regional%20profiles%20Italy%20-%20revised.pdf

Fairtlough, G. (1994). Organizing for innovation: Compartments, competences and networks. *Long Range Planning*. https://doi.org/10.1016/0024-6301(94)90193-7

Giddens, A. (2015). The politics of climate change. *Policy and Politics*. https://doi.org/10.1332/030557315X14290856538163

Hahladakis, J. N., & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials*. https://doi.org/10.1016/j.jhazmat.2019.120887

Holmberg, J. (1998). Backcasting: A Natural Step in Operationalising Sustainable Development. *Greener Management International*. https://doi.org/10.1080/00393277408587587

Iacovidou, E., Velis, C. A., Purnell, P., Zwirner, O., Brown, A., Hahladakis, J., … Williams, P. T. (2017). Metrics for optimising the multi-dimensional value of resources recovered from waste in a circular economy: A critical review. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.07.100

Jacob, K., Binder, M., & Wieczorek, A. (2004). Knowledge for the Sustainability Transition. The Challenge for Social Science. In *Proceedings of the 2002 Berlin Conference on the Human Dimensions of Global Environmental Change.*

Kishita, Y., Mizuno, Y., & Umeda, Y. (2016). Scenario Design Approach to Envisioning Sustainable Manufacturing Industries to 2050. In *Procedia CIRP*. https://doi.org/10.1016/j.procir.2016.04.103

Kok, K., van Vliet Mathijs, M., Bärlund Ilona, I., Dubel, A., & Sendzimir, J. (2011). Combining participative backcasting and exploratory scenario development: Experiences from the SCENES project. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2011.01.004

Lawless, M. W., & Anderson, P. C. (1996). Generational technological change: Effects of innovation and local rivalry on performance. *Academy of Management Journal*. https://doi.org/10.2307/256996

Mokyr J. (1990) The Lever of Riches. Technological Creativity and Economic Progress. Oxford University Press, New York, NY.

Moulaert, F., & Sekia, F. (2003). Territorial innovation models: A critical survey. *Regional Studies*. https://doi.org/10.1080/0034340032000065442

OECD (1997). National Innovation Systems. Available online: https://www.oecd.org/science/inno/2101733.pdf

OECD (2011). Regions and innovation policy, OECD Reviews of regional innovation, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264097803-en

OECD (2013). Region and Innovation: collaborating aross borders, OECD Reviews of Regional Innovation, OECD Publishing. http://dx.doi.org/10.1787/9789264205307-en

Quist, J. (2007). Backcasting for a sustainable future: the impact after 10 years. Analysis.

Quist, J., & Vergragt, P. (2006). Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. *Futures*. https://doi.org/10.1016/j.futures.2006.02.010

Rahimifard, S., Sheldrick, L., Woolley, E., Colwill, J., & Sachidananda, M. (2013). How to Manufacture a Sustainable Future for 9 Billion People in 2050. In *Re-engineering Manufacturing for Sustainability*. https://doi.org/10.1007/978-981-4451-48-2_1

Raven, R., Van Den Bosch, S., & Weterings, R. (2010). Transitions and strategic niche management: Towards a competence kit for practitioners. *International Journal of Technology Management.* https://doi.org/10.1504/IJTM.2010.033128

Robinson, J. B. (1990). Futures under glass. A recipe for people who hate to predict. *Futures*. https://doi.org/10.1016/0016-3287(90)90018-D

Roorda, C., Wittmayer, J., Henneman, P., van Steenbergen, F., Frantzeskaki, N., & Loorbach, D. (2014). Transition Management in the Urban Context: Guidance Manual. Drift, Erasmus Universiteit Rotterdam.

Vergragt, P. J., & Jansen, L. (1993). Sustainable technological development: The making of a dutch long-term oriented technology programme. *Project Appraisal*. https://doi.org/10.1080/02688867.1993.9726902

Vergragt, P. J., Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2011.03.010

Unioncamere (2019). Rapporto 2019 sull'economia regionale. Available online: https://www.ucer.camcom.it/studi-ricerche/analisi/rapporto-economia-regionale/pdf/2015/2019-rapporto-economia-regionale.pdf

─ Chapter 2

Aguado, J., Serrano, D.P. and San Miguel, G. (2018). European trends in the feedstock recycling of plastic wastes. *Global NEST Journal* https://doi.org/10.30955/gnj.000432

Álvarez-Chávez, C. R., Edwards, S., Moure-Eraso, R., & Geiser, K. (2012). Sustainability of bio-based plastics: General comparative analysis and recommendations for improvement. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2011.10.003

Bernardo, C. A., Simões, C. L., & Pinto, L. M. C. (2016). Environmental and economic life cycle analysis of plastic waste management options. A review. In *AIP Conference Proceedings* (Vol. 1779, No. 1, p. 140001). AIP Publishing. Available at: https://aip.scitation.org/doi/pdf/10.1063/1.4965581.

Brooks, A. L., Wang, S., & Jambeck, J. R. (2018). The Chinese import ban and its impact on global plastic waste trade. *Science Advances*. https://doi.org/10.1126/sciadv.aat0131

Carpenter, E. and Wolverton, S. (2017). Plastic litter in streams: The behavioural archaeology of a pervasive environmental problem. *Applied Geography*, 84, 93-101. https://doi.org/10.1016/j.apgeog.2017.04.010

Chiba, S., Saito, H., Fletcher, R., Yogi, T., Kayo, M., Miyagi, S., … Fujikura, K. (2018). Human footprint in the abyss: 30 year records of deep-sea plastic debris. *Marine Policy*. https://doi.org/10.1016/j.marpol.2018.03.022

Cole, M., Lindeque, P., Halsband, C., and Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: a review. *Mar. Pollut. Bull*., 62, 2588-2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

D'ambrières, W. (2019). Plastics recycling worldwide: Current overview and desirable changes. *Field Actions Science Report*.

Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulletin*. https://doi.org/10.1016/S0025-326X(02)00220-5

Di Gregorio, B.E. (2009). Biobased Performance Bioplastic: Mirel. Chemistry & Biology Innovations. Http://doi.org/10.1016/j.chembiol.2009.01.001

European Bioplastics & Institute for Bioplastics and Biocomposites (2017). Bioplastics market data. European Bioplastics. Available online: https://www.european-bioplastics.org/wp-content/uploads/2016/02/Report_Bioplastics-Market-Data_2018.pdf

European Parliament and of the Council (2006). Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

European Parliament and of the Council (2019). Directive (Eu) 2019/904 Of The European Parliament And Of The Council Of 5 June 2019 On The Reduction of the impact of certain plastic products on the environment. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN

Galloway, T. S. (2015). Micro- and nano-plastics and human health. In *Marine Anthropogenic Litter*. https://doi.org/10.1007/978-3-319-16510-3_13

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*. https://doi.org/10.1126/sciadv.1700782

Gregory, M.R., Andrady, A.L. (2003). Plastics in the marine environment. In *Andrady, Anthony.L. (Ed.)*, Plastics and the Environment. John Wiley and Sons, ISBN 0- 471-09520-6.

Harper, C. A. (2005). Handbook of Plastic Processes. *Handbook of Plastic Processes*. http://doi.org/10.1002/0471786586

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2008.0311

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347, 768-771.

Karana, E. (2012). Characterization of "natural" and "high-quality" materials to improve perception of bio-plastics. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2012.07.034

Landon-Lane, M. (2018). Corporate social responsibility in marine plastic debris governance. *Marine Pollution Bulletin*, 127, 310-319. https://doi.org/10.1016/j.marpolbul.2017.11.054

Lavers, J.L. and Bond, A.L. (2017). Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. Proc. Natl. Acad. Sci. Unit. States Am. (2017). https://doi.org/10.1073/pnas.1619818114

Lithner, D., Larsson, A., & Dave, G. (2011). Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2011.04.038

Miller, R.Z., Watts, A.J.R., Winslow, B.O., Galloway, T.S., and Barrows, A.P.W. (2017). Mountains to the sea: River study of plastic and non-plastic microfiber pollution in the northeast USA. *Marine Pollution Bulletin*, 124 (1), 245-251. https://doi.org/10.1016/j.marpolbul.2017.07.028

Mojo, S. (2007). Compostable products: Designing for disposal. *Journal of Polymers and the Environment*, 15(4), 289–294.

Monteiro, R. C. P., Ivar do Sul, J. A., & Costa, M. F. (2018). Plastic pollution in islands of the Atlantic Ocean. *Environmental Pollution*. https://doi.org/10.1016/j.envpol.2018.01.096

Ng, E.L., Lwanga, E.H., Eldridge, S.M., Johnston, P., Hu, H.W., Geissen, V., and Chen, D. (2018). An overview of microplastic and nanoplastic pollution in agroecosystems. *Science of The Total Environment*, 627, 1377-1388. https://doi.org/10.1016/j.scitotenv.2018.01.341

OCED (2004). Emission scenario document on plastic additives. Series on emission scenario documents No. 3. Paris. Environmental Directorate. *OECD Environmental Health and Safety Publications*.

PlasticsEurope (2015). Plastics – the facts 2015. Available online: https://www.plasticseurope.org/application/files/3715/1689/8308/2015plastics_the_fa cts_14122015.pdf

PlasticsEurope (2016). Plastics – the facts 2016. Available online: https://www.plasticseurope.org/application/files/4315/1310/4805/plastic-the-fact-2016.pdf

PlasticsEurope (2017). Plastics – the Facts 2017. Available online: https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

PlasticsEurope (2018). Plastics – the facts 2018. Available online: https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

PlasticsEurope (2019). Plastics – the facts 2019. Available online: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

Rosato, D. V., Rosato, D. V., & Rosato, M. G. (2000). Injection molding handbook. Kluwer Academic Publisher. http://doi.org/10.1007/978-1-4615-4597-2

Roy, C. D., & Brown, H. C. (2007). A comparative study of the relative stability of representative chiral and achiral boronic esters employing transesterification. *Monatshefte Fur Chemie*. https://doi.org/10.1007/s00706-007-0699-x

Seltenrich, N. (2015). New link in the food chain? Marine plastic pollution and seafood safety. *Environmental Health Perspectives*. https://doi.org/10.1289/ehp.123-A34

The European House – Ambrosetti (2013). L'eccellenza della filiera della plastica per il rilancio industrial dell'Italia e dell'Europa. Available online: https://www.ambrosetti.eu/wp-content/uploads/130907_Filiera_della_plastica_Ricerca_completa_HD.pdf

UNEP (2014). Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry; UNEP. http://wedocs.unep.org/handle/20.500.11822/9238

Villanueva, A., Eder, P. (2014). End-of-Waste criteria for waste plastic for conversion. Technical proposal. European Union, Luxembourg. Report EUR 26843 EN. Available online: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/end-waste-criteria-waste-plastic-conversion-technical-proposals

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environmental Pollution (Barking, Essex : 1987).*

– Chapter 3

ANCI (2019). La banca dati. VIII Rapporto raccolta differenziata e riciclo 2018. Available online: http://www.anci.it/wp-content/uploads/VIII-Rapporto-Raccolta-Differenziata-e-Riciclo-2018-1.pdf

Angellier-Coussy, H., Guillard, V., Guillaume, C., & Gontard, N. (2013). Role of packaging in the smorgasbord of action for sustainable food consumption. *Agro Food Industry Hi-Tech*.

APME (2001). Plastics. A material of choice for the packaging industry. Insight into consumption and recovery in Western Europe APME.

ARGUS (2001). European Packaging Waste Management Systems. Final Report, European Commission, Brussels. Available online: https://ec.europa.eu/environment/waste/studies/packaging/epwms.pdf

Chen, S.-J., Ma, Y.-J J., Wang, M., Tian, X.-J. Luo, D. Chen, B.-X. Mai (2010). Measurement and human exposure assessment of brominated flameretardants in household products from South China, *J. Hazard. Mater.* 176, 979–984.

Cherif Lahimer, M., Ayed, N., Horriche, J., & Belgaied, S. (2017). Characterization of plastic packaging additives: Food contact, stability and toxicity. *Arabian Journal of Chemistry*. https://doi.org/10.1016/j.arabjc.2013.07.022

CONAI (2017). Packaging recovery in Italy: The CONAI system. Available online: http://www.conai.org/wp-content/uploads/2014/09/The-CONAI-System_-2017.pdf

CONAI (2018). Liste degli imballaggi in plastica nelle fasce contributive.

CONAI (2019). Liste degli imballaggi in plastica nelle fasce contributive.

CONAI (2020). Liste degli imballaggi in plastica nelle fasce contributive. Available online: http://www.conai.org/wp-content/uploads/2020/02/Lista_imballaggi_plastica_nelle_fasce_contributive_2020.pdf

COREPLA (2018). Rapporto sulla gestione 2017. Available online: http://www.corepla.it/documenti/4646a702-7746-46ba-a0d5-f4497a656d25/Relazione+sulla+gestione.pdf

COREPLA (2019). Rapporto sulla gestione 2018. Available online: http://www.corepla.it/documenti/c3cc963b-c446-46c3-809b-e17e487f8e2d/RELAZIONE+SULLA+GESTIONE+2018.pdf

D'ambrières, W. (2019). Plastics recycling worldwide: Current overview and desirable changes. *Field Actions Science Report*.

Dainelli, D., Gontard, N., Spyropoulos, D., Zondervan-van den Beuken, E., & Tobback, P. (2008). Active and intelligent food packaging: legal aspects and safety concerns. *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2008.09.011

Deloitte Sustainability (2017). Plastics Recyclers Europe; Blueprint for plastics packaging waste: Quality sorting & recycling. Available online: https://www.plasticsrecyclers.eu/sites/default/files/PRE_blueprint%20packaging%20waste_Final%20report%202017.pdf

Ellen MacArthur Foundation (2017). The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action. Ellen MacArthur Foundation. https://doi.org/10.1103/Physrevb.74.035409

Eurometaux (2016). A single EU calculation method for measuring real recycling rates. Available online: https://eurometaux.eu/media/1596/eurometaux-qa-on-recycling-rate-calculation.pdf

European Commission (2012). Use Of Economic Instruments And Waste Management Performances Available online: https://ec.europa.eu/environment/waste/pdf/final_report_10042012.pdf

European Commission (2014). Development of Guidance on Extended Producer Responsibility (EPR). Available online: https://ec.europa.eu/environment/waste/pdf/target_review/Guidance%20on%20EPR%20-%20Final%20Report.pdf

European Commission (2016). Study on assessing the environmental fiscal reform potential for the EU28. Available online: https://ec.europa.eu/environment/integration/green_semester/pdf/Eunomia%20EFR%20Final%20Report%20MAIN%20REPORT.pdf

European Commission (2018). A European Strategy for plastics in a circular economy. Available online: https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf

European Parliament and Council (1994). European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31994L0062&from=en

European Commission (2019d). Commission Staff Working Document. Sustainable Products in a Circular Economy - Towards an EU Product Policy Framework contributing to the Circular Economy. Available online: https://ec.europa.eu/environment/circular-economy/pdf/sustainable_products_circular_economy.pdf

European Parliament and of the Council (2019). Directive (Eu) 2019/904 Of The European Parliament And Of The Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN

European Technical Group on Sustainable Finance (2019). Taxonomy. Technical Report. Available online: https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/190618-sustainable-finance-teg-report-taxonomy_en.pdf

Fondazione Per lo sviluppo sostenibile (2019). L'Italia del Riciclo 2019. Available online: https://www.fondazionesvilupposostenibile.org/wp-content/uploads/dlm_uploads/L%E2%80%99Italia-del-Riciclo-2019.pdf

Gent, M. R., Menendez, M., Toraño, J., & Diego, I. (2009). Recycling of plastic waste by density separation: Prospects for optimization. *Waste Management and Research*. https://doi.org/10.1177/0734242X08096950

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*. https://doi.org/10.1016/j.jhazmat.2017.10.014

ISO (2013). ISO 18601:2013. Packaging and the environment. General requirements for the use of ISO standards in the field of packaging and the environment.

ISPRA (2019). Rapporto rifiuti urbani. Edizione 2019. Available online: http://www.isprambiente.gov.it/files2019/pubblicazioni/rapporti/RapportoRifiutiUrbani_VersioneIntegralen313_2019_agg17_12_2019.pdf

Istituto nazionale imballaggio (2018). Continua il trend positivo del settore packaging. Available online: https://www.istitutoimballaggio.it/press/

Italian government (2006). Decreto legislativo 3 aprile 2006, n. 152. Available online: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2006-04-14&atto.codiceRedazionale=006G0171

Italian government (2019). Decreto legge 30 aprile 2019, n. 34. Misure urgenti di crescita economica e per la risoluzione di specifiche situazioni di crisi. Available online: https://www.gazzettaufficiale.it/eli/id/2019/04/30/19G00043/sg

Italian government (2020a). Legge 27 dicembre 2019, n. 160. *Bilancio di previsione dello Stato per l'anno finanziario 2020 e bilancio pluriennale per il triennio 2020-2022.* Available online: https://www.gazzettaufficiale.it/atto/stampa/serie_generale/originario

Italian government (2020b). Decreto Legge Misure Urgenti Per Il Contrasto Dei Cambiamenti Climatici E La Promozione Dell'economia Verde. Availble online: http://www.rinnovabili.it/wp-content/uploads/2019/09/Bozza-decreto-Clima.pdf

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347, 768-771.

Joint Research Centre (2017). Top Marine Beach Litter Items in Europe. Available online: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108181/technical_report_top_marine_litter_items_eur_29249_en_pdf.pdf

Kaffine, D and O'Reilly, P. (2015) What Have We Learned About Extended Producer Responsibility in the Past Decade? A Survey of the Recent EPR Economic Literature. OECD.

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2006). Action Plan For The Environmental Sustainability Of Consumption In The Public Administration Sector. Available online: https://www.minambiente.it/sites/default/files/archivio/allegati/GPP/all.to_21_PAN_GPP_definitivo_EN.pdf

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2014). Direttore Generale per la tutela del territorio e delle risorse idriche 5201/2014. *Riconoscimento del sistema P.A.R.I. secondo il progetto elaborato e proposto dalla società Aliplast S.p.a.* . Available online: https://www.minambiente.it/sites/default/files/archivio/normativa/dm_04_08_2014_5201.pdf

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2016). Decreto del Direttore Generale per i rifiuti e l'inquinamento 28/2016, recante. *Accoglimento dell'istanza di riconoscimento del sistema di riciclaggio, recupero, ripresa e raccolta dei pallet in plastica CONIP.* Available online: https://www.minambiente.it/sites/default/files/archivio/normativa/dd_rin_08_04_2016_28.pdf

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2018). Decreto del Direttore Generale per i rifiuti e l'inquinamento 58/2018. *Riconoscimento del sistema autonomo CoRiPET.* Available online: https://www.minambiente.it/sites/default/files/archivio/normativa/rifiuti/dd_CoRiPET_58_2018.pdf

Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2019). Linee guida per i Sistemi autonomi di gestione degli imballaggi. Available online: https://www.minambiente.it/sites/default/files/archivio/allegati/rifiuti/LineeGuidaSistemiAutonomi.pdf

Newinnonet (2015). Analysis of the plastic packaging value chain. Available online: http://www.newinnonet.eu/downloads/D%202.4_RP_Report%20summarising%20the%20analysis%20of%20the%20plastic%20packaging%20value%20chain2.pdf

Ocean Conservancy (2019). International Coastal Cleanup Report. Available online: https://oceanconservancy.org/wp-content/uploads/2019/09/Final-2019-ICC-Report.pdf

OECD (2001) Extended Producer Responsibility: A Guidance Manual for Governments, OECD, March, Paris.

Orzolek, M., D. (2017). A Guide to the Manufacture, Performance, and Potential of Plastics in Agriculture. *Science direct.*

PlasticsEurope (2018). Plastics – the facts 2018. Available online: https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

PlasticsEurope (2019). Plastics – the facts 2019. Available online: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

PlasticsRecyclersEurope (2015). Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment. Available online: https://www.plasticsrecyclers.eu/sites/default/files/BIO_Deloitte_PRE_Plastics%20Recycling%20Impact_Assesment_Final%20Report.pdf

Pongracz, E. (1998). The Environmental Effects of Packaging. Licentiate thesis. Tampere University of Technology, Department of Environmental Technology, Institute of Environmental Engineering and Biotechnology, Tampere, Finland.

Azzurro P., Berardi D., Valli N. (2020). Rifiuti e responsabilità estesa del produttore: imparando dall'Europa. Laboratorio REF Ricerche. Available online: file:///C:/Users/utente/Downloads/Contributo_n.142%20def.pdf

Reloop (2017). Fact Sheet: Deposit Return System: System Performance https://reloopplatform.eu/wp-content/uploads/2018/05/Fact-Sheet-Performance-17MAY2017.pdf

Restuccia, D., Spizzirri, U. G., Parisi, O. I., Cirillo, G., Curcio, M., Iemma, F., … Picci, N. (2010). New EU regulation aspects and global market of active and intelligent packaging for food industry applications. *Food Control*. https://doi.org/10.1016/j.foodcont.2010.04.028

Steinhilper, R., Hieber, M., & Osten - Sacken, D. v. d. (1997). Decision Management Systems for Downcycling/Upcycling/Eco Design- Interdisciplinary Experiences -. In *Life Cycle Networks*. https://doi.org/10.1007/978-1-4615-6381-5_27

UNEP (2014) Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry.

UNEP (2015). Stockholm Convention on Persistent Organic Pollutants. Relevance of BFRs and thermal conditions on theformation pathways of brominated and brominated–chlorinateddibenzodioxins and dibenzofurans, *Environ. Int.* 29 (2003) 699–710.

UNEP (2018). Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations. Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/27113/plastics_limits.pdf

US EPA (1997). Chemical Industry National Environmental Baseline Report 1990 to 1994, Washington D.C.

Verghese, K., Lewis H. (2007) Environmental innovation in industrial packaging: a supply chain approach, *International Journal of Production Research*, 45:18-19, 4381-4401, DOI: 10.1080/00207540701450211

Villanueva, A., Eder, P. (2014). End-of-Waste criteria for waste plastic for conversion. Technical proposal. Available online: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/end-waste-criteria-waste-plastic-conversion-technical-proposals

Watkins, E., Hogg, D., Mitsios, A., Mudgal, S., Neubauer A., Reisinger, H., Troeltzsch, J., Acoleyen, V., M. (2012). Use of economic instruments and waste management performances. Bio Intelligence service. Available online: https://ec.europa.eu/environment/waste/pdf/final_report_10042012.pdf

Watkins, E., Gionfra, S., Schweitzer, J-P., Pantzar, M., Janssens, C.,ten Brink, P. (2017). EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging.

Wilts, H., von Gries, N., & Bahn-Walkowiak, B. (2016). From waste management to resource efficiency-the need for policy mixes. *Sustainability (Switzerland)*. https://doi.org/10.3390/su8070622

WRAP (2009). Commercial scale mixed plastics recycling. A report on the technical viability of recycling mixed plastic packaging waste from domestic sources on a commercial scale in the U.K.

WRAP (2011). Development of NIR Detectable Black Plastic Packaging. Available online: http://www.wrap.org.uk/sites/files/wrap/Recyclability%20of%20black%20plastic%20packaging.pdf

– Chapter 4

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*. https://doi.org/10.1016/j.wasman.2009.06.004

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*. 33:5, 308-320, https://doi.org/10.1080/21681015.2016.1172124

De Bruyn, S. M., & Opschoor, J. B. (1997). Developments in the throughput-income relationship: Theoretical and empirical observations. *Ecological Economics*. https://doi.org/10.1016/S0921-8009(96)00086-9

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental Protection*. https://doi.org/10.4236/jep.2015.610096

Ellen MacArthur Foundation (2017). New plastics economy. Catalysing action. Available online: https://www.ellenmacarthurfoundation.org/assets/downloads/New-Plastics-Economy_Catalysing-Action_13-1-17.pdf

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., … Rifman, S. (2013). Plastic pollution in the South Pacific subtropical gyre. *Marine Pollution Bulletin*. https://doi.org/10.1016/j.marpolbul.2012.12.021

European Parliament and of the Council (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=IT

Finnveden, G., Ekvall, T., Arushanyan, Y., Bisaillon, M., Henriksson, G., Gunnarsson Östling, U., … Guath, M. (2013). Policy Instruments towards a Sustainable Waste Management. Sustainability. https://doi.org/10.3390/su5030841

Gentil, E. C., Gallo, D., & Christensen, T. H. (2011). Environmental evaluation of municipal waste prevention. *Waste Management*. https://doi.org/10.1016/j.wasman.2011.07.030

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2015.09.007

Hahladakis, J. N., & Iacovidou, E. (2018). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2018.02.330

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2017.09.005

Laner, D., & Rechberger, H. (2009). Quantitative evaluation of waste prevention on the level of small and medium sized enterprises (SMEs). *Waste Management*. https://doi.org/10.1016/j.wasman.2008.05.007

Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., … Schludermann, E. (2014). The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. *Environmental Pollution*. https://doi.org/10.1016/j.envpol.2014.02.006

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2015.12.042

Lithner D. (2011). Environmental and health hazards of chemicals in plastic polymers and products. PhD Teshis.

Murphy, J. (2001). Additives for Plastics Handbook. *Additives for Plastics: State of the Art*. https://doi.org/10.1016/B978-185617370-4/50025-7

Nessi, S., Rigamonti, L., & Grosso, M. (2013). Discussion on methods to include prevention activities in waste management LCA. *International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-013-0570-8

Price, J. L., & Joseph, J. B. (2000). Demand management - a basis for waste policy: A critical review of the applicability of the waste hierarchy in terms of achieving sustainable waste management. *Sustainable Development*. https://doi.org/10.1002/(SICI)1099-1719(200005)8:2<96::AID-SD133>3.0.CO;2-J

Rosato, D. V. (2011). Extruding Plastics. *Extruding Plastics*. https://doi.org/10.1007/978-1-4615-5793-7

Saphire, D. (1994). Delivering the Goods: Benefits of Reusable Shipping Containers. INFORM, Inc.: New York, NY.

Smithers Pira. (2017). The Future of Global Packaging to 2022. Market Reports.

Tencati, A., Pogutz, S., Moda, B., Brambilla, M., & Cacia, C. (2016). Prevention policies addressing packaging and packaging waste: Some emerging trends. *Waste Management*. https://doi.org/10.1016/j.wasman.2016.06.025

Vancini F. (2000) Strategic waste prevention, OECD reference manual. Available online: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/epoc/ppc(2000)5/final

Wilts, H. (2012). National waste prevention programs: Indicators on progress and barriers. *Waste Management and Research*. https://doi.org/10.1177/0734242X12453612

Zorpas, A. A., Voukkali, I., & Loizia, P. (2017). Effectiveness of waste prevention program in primary students' schools. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-017-8968-7

─ Chapter 5

Bontempi, E. (2017). A new approach to evaluate the sustainability of raw materials substitution. In *Springer Briefs in Applied Sciences and Technology*. https://doi.org/10.1007/978-3-319-60831-0_4

Bourguignon D. (2016). Closing the loop New circular economy package. European Parliamentary Research Service. doi:10.1111/j.1742-1241.2010.02575

Emilia Romagna Region (2019). Strategia Regionale Per La Riduzione Dell'incidenza Delle Plastiche Sull'ambiente. Available online: http://servizissiir.regione.emilia-romagna.it/deliberegiunta/servlet/AdapterHTTP?action_name=ACTIONRICERCADELIBERE&operation=leggi&cod_protocollo=GPG/2019/1205&ENTE=1

European Commission (2008). Regulation (EC) No 282/2008 of 27 March 2008 on Recycled Plastic Materials and Articles Intended to Come into Contact with Foods and Amending Regulation (EC) No 2023/2006 (Text with EEA Relevance). Available online: https://eurlex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0282&from=EN

European Commission (2015). An EU Action Plan for the Circular Economy. COM (2015) 614. Available online: https://doi.org/10.1017/CBO9781107415324.004

European Commission (2018). A European Strategy for Plastics in a Circular Economy. Available online: https://doi.org/10.1021/acs.est.7b02368

European Commission (2018). Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions A European Strategy for Plastics in a Circular Economy Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN

European Commission (2019a). Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions. *The European Green Deal*. Available online: https://ec.europa.eu/info/publications/communication-european-green-deal_en

European Commission (2019d). Commission Staff Working Document. Sustainable Products In A Circular Economy - Towards An Eu Product Policy Framework Contributing To The Circular Economy. Available online: https://ec.europa.eu/environment/circular-economy/pdf/sustainable_products_circular_economy.pdf

European Parliament and the Council of the European Union (2015). Directive (EU) 2015/720 of 29 April 2015 amending Directive 94/62/EC as regards Reducing the Consumption of Lightweight Plastic Carrier Bags. Available online: https://doi.org/http://eurlex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf

European Parliament and the Council of the European Union (2018). Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 Amending Directive 94/62/EC on Packaging and Packaging Waste Available online: https://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32018L0852&from=EN

EXPRA (2015). Analysis of Eurostat packaging recycling data a study of the years 2006-2012. Available online: http://www.expra.eu/uploads/downloads/20151015%20Analysis%20of%20Eurostat%20packaging%20recycling%20data%201%200%20with%20cover26.10.pdf

Fischer-Kowalski, M., Amann, C. (2001). Beyond IPAT and Kuznets curves: globalization as a vital factor in analysing the environmental impact of socioeconomic metabolism. *Popul. Environ*. 23 (1), 7–47. https://doi.org/10.1023/A:1017560208742

Parlow, A. (2014). Environmental Pressure and Armed Conflict - Is there an Empirical Kuznets Curve for Myanmar? *Journal of Global Economics*. https://doi.org/10.4172/2375-4389.1000111

Quist, J. (2007). Backcasting for a sustainable future: the impact after 10 years. Analysis.

Quist, J., & Vergragt, P. (2006). Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. *Futures*. https://doi.org/10.1016/j.futures.2006.02.010

Regione Emilia Romagna (2015). Legge Regionale n. 16 del 5 ottobre 2015 "Disposizioni a sostegno dell'economia circolare, della riduzione della promozione dei rifiuti urbani, del riuso dei beni a fine vita, della raccolta differenziata e modifiche alla Legge Regionale 19 agosto 1996 n. 31.

Regione Emilia-Romagna (2016). Deliberazione Dell'assemblea Legislativa Della Regione Emilia-Romagna 3 Maggio 2016, N. 67. Decisione sulle osservazioni pervenute e approvazione del Piano regionale di gestione dei rifiuti (PRGR).

Seppälä, T., Haukioja, T., Kaivo-oja, J. (2001). The EKC Hypothesis does not hold fordirect material flows: environmental Kuznets Curve Hypothesis tests for direct material flows in five industrial countries. *Popul. Environ*. 23 (2), 217–238.

Tsiamis, D. A., Torres, M., & Castaldi, M. J. (2018). Role of plastics in decoupling municipal solid waste and economic growth in the U.S. *Waste Management*. https://doi.org/10.1016/j.wasman.2018.05.003

UNEP (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. (2018). In *A New Era in Global Health*. https://doi.org/10.1891/9780826190123.ap02

Van Ewijk, S., & Stegemann, J. A. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2014.11.051

Velis, C. A., & Brunner, P. H. (2013). Recycling and resource efficiency: It is time for a change from quantity to quality. *Waste Management and Research.* https://doi.org/10.1177/0734242X13489782

Worrell, E., Reuter, M. A. (2014). Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists. *Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists*. https://doi.org/10.1016/C2011-0-07046-1

Zorpas, A. A., Voukkali, I., & Loizia, P. (2017). Effectiveness of waste prevention program in primary students' schools. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-017-8968-7

– Chapter 6

ANCI (2019). La banca dati. VIII Rapporto raccolta differenziata e riciclo 2018. Available online: http://www.anci.it/wp-content/uploads/VIII-Rapporto-Raccolta-Differenziata-e-Riciclo-2018-1.pdf

De Vicente, L., Javier and Matti, Cristian (2016). Visual toolbox for system innovation. A resource book for practitioners to map, analyse and facilitate sustainability transitions. Transitions Hub Series. Climate-KIC, Brussels 2016. ISBN 978-2-9601874-0-3

Edquist, C. (2001). The Systems of Innovation Approach and Innovation Policy: An account of the state of the art. *DRUID Conference, Aalborg*.

Edquist, C. and Johnson, B. (1997). Institutions and organisations in systems of innovation. *Systems of Innovation: Technologies, Institutions and Organizations.* London and Washington: Pinter/Cassell Academic.

Forsyth, S., & Brooks, D. B. (2011). Applying water soft path analysis in an agricultural region of Canada. *Water International*. https://doi.org/10.1080/02508060.2011.628568

Ingelstam, L. (2002). Systems - to think about society and technology; System - att taenka oever samhaelle och teknik. Technical Report. STEM-EB-1-2002

Kok, K., van Vliet Mathijs, M., Bärlund Ilona, I., Dubel, A., & Sendzimir, J. (2011). Combining participative backcasting and exploratory scenario development: Experiences from the SCENES project. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2011.01.004

Lelea, M.A., G.M. Roba, A. Christinck, B. Kaufmann. (2014). Methodologies for stakeholder analysis – for application in transdisciplinary research projects focusing on actors in food supply chains. German Institute for Tropical and Subtropical Agriculture (DITSL).

Long, N. (1990). From Paradigm Lost to Paradigm Regained? The Case for an Actor-oriented Sociology of Development. European Review of Latin American and Caribbean Studies 49: 3-24.

Rickne, A. (2000). New Technology-Based Firms and Industrial Dynamics: Evidence from the Technological Systems of Biomaterials in Sweden, Ohio and Massachusetts, Department of Industrial dynamics, Chalmers University of Technology.

Scholl, H. J. (2001). Applying stakeholder theory to e-government: Benefits and limits. In *IFIP Advances in Information and Communication Technology*.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis and Strategic Management*. https://doi.org/10.1080/09537320802292651

Soliva, R., Rønningen, K., Bella, I., Bezak, P., Cooper, T., Flø, B. E., … Potter, C. (2008). Envisioning upland futures: Stakeholder responses to scenarios for Europe's mountain landscapes. *Journal of Rural Studies*. https://doi.org/10.1016/j.jrurstud.2007.04.001

Zimmermannn, A., C. Maennling. (2007). Mainstreaming Participation: Multi-stakeholder management: Tools for Stakeholder Analysis: 10 Building Blocks for Designing Participatory Systems of Cooperation. Promoting Participatory Development in German Development Cooperation. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ). Available online: http://www.fsnnetwork.org/sites/default/files/en-svmp-instrumente-akteuersanalyse.pdf

─ Chapter 7

Aarts, W. (1997). Voorbeelden van Duurzame Technologische Ontwikkelingen vergeleken (examples of sustainable technological developments compared). STD working document DTO3, Delft, The Netherlands.

Aguilar, F.J. (1967). Scanning the business environment. New York: MacMillan Co.

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*. https://doi.org/10.1016/j.wasman.2009.06.004

APME (2001). Plastics. A material of choice for the packaging industry. Insight into consumption and recovery in Western Europe.

ARPAE (2018). La gestione dei rifiuti in Emilia-Romagna. Report 2018. Available online: https://www.arpae.it/dettaglio_documento.asp?id=7456&idlivello=1443

Assink, M. (2006). Inhibitors of disruptive innovation capability: A conceptual model. *European Journal of Innovation Management*. https://doi.org/10.1108/14601060610663587

Astrup, T., Fruergaard, T., & Christensen, T. H. (2009). Recycling of plastic: Accounting of greenhouse gases and global warming contributions. Waste Management and Research. https://doi.org/10.1177/0734242X09345868

Baillie, C., Matovic, D., Thamae, T., & Vaja, S. (2011). Waste-based composites - Poverty reducing solutions to environmental problems. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2011.05.006

Bartl, A. (2014). Moving from recycling to waste prevention: A review of barriers and enables. *Waste Management and Research*. https://doi.org/10.1177/0734242X14541986

Brems, A., Baeyens, J., & Dewil, R. (2012). Recycling and recovery of post-cet alonsumer plastic solid waste in a European context. *Thermal Science*. https://doi.org/10.2298/TSCI120111121B

CE Delft (2019). Verkenning chemische recycling - update 2019 Hoe groot zijn - en worden - de kansen voor klimaatbeleid? Available online: file:///C:/Users/utente/Downloads/CE_Delft_2P22_Verkenning_chemische_recycling_Update2019.pdf

Charter M. and Tischner U. (2001), Sustainable Solutions – Developing products and services for the future, Greenleaf publishing, UK, 2001.

COREPLA (2018). Rapporto sulla gestione 2018. Available online: http://www.corepla.it/documenti/c3cc963b-c446-46c3-809b-e17e487f8e2d/RELAZIONE+SULLA+GESTIONE+2018.pdf

Crippa, M., De Wilde, B., Koopmans, R., Leyssens, J., Muncke, J., Ritschkoff A-C., Van Doorsselaer, K., Velis, C. & Wagner, M. A (2019). Circular economy for plastics – Insights from research and innovation to inform policy and funding decisions, European Commission, Brussels, Belgium

Crowther, P., and Donlan, L. (2011). Value-creation space : the role of events in a service-dominant marketing paradigm. Journal of Marketing Management, 27 (13-14), 1444-1463.

De Vicente, L., Javier and Matti, Cristian (2016). Visual toolbox for system innovation. A resource book for practitioners to map, analyse and facilitate sustainability transitions. Transitions Hub Series. Climate-KIC, Brussels 2016. ISBN 978-2-9601874-0-3.

Delgado, L., Catarino, A., S., Eder, P., Litten, D., Luo, Z., Villanueva A. (2009). End-of-Waste Criteria Final Report. European Commission Joint Research Centre Institute for Prospective Technological Studies Available online: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC53238/jrc53238.pdf

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental Protection*. https://doi.org/10.4236/jep.2015.610096

European Commission (2008). Regulation (EC) No 282/2008 of 27 March 2008 on Recycled Plastic Materials and Articles Intended to Come into Contact with Foods and Amending Regulation (EC) No 2023/2006 (Text with EEA Relevance). Available online: https://eurlex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0282&from=EN

European Commission (2012). Use Of Economic Instruments And Waste Management Performances Available online: https://ec.europa.eu/environment/waste/pdf/final_report_10042012.pdf

European Parliament and of the Council (2006). Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1907&from=EN

European Parliament and of the Council (2005). Commission Decision of 22 March 2005 establishing the formats relating to the database system pursuant to Directive 94/62/EC of the on packaging and packaging waste. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32005D0270&from=EN

European Parliament and of the Council (2017). Directive (EU) 2017/2102 of the European Parliament and of the Council of 15 November 2017 amending Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017L2102&from=EN

European Parliament and the Council of the European Union (2015). Directive (EU) 2015/720 of 29 April 2015 amending Directive 94/62/EC as regards Reducing the Consumption of Lightweight Plastic Carrier Bags. Available online: https://doi.org/http://eurlex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf

European Parliament and of the Council (2018). Commission Implementing Decision (EU) 2018/1147 of 10 August 2018 establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75/EU of the European Parliament and of the Council. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D1147&from=EN

Fisher, M.M., Mark, F.E., Kingsbury, T., Vehlow, J., Yamawaki, T., (2005). Energy recovery in the sustainable recycling of plastics from end-of-life electrical and electronic products. In *Proceedings of the 2005 IEEE International Symposium on Electronics and the Environment.*

Foschi, E., Bonoli. A. (2019). The Commitment of Packaging Industry in the Framework of the European Strategy for Plastics in a Circular Economy. *Administrative Science Journal*. doi:10.3390/admsci9010018

Foschi, E., D'Addato, F., Bonoli., A., Ratta., M. (2020). Scenario of the plastic waste recycling in Emilia Romagna Region (Italy) as effort for the recent European Strategy for plastics in a circular economy. *Environmental Science & Pollution Research* (in press)

Hahladakis, J. N., Purnell, P., Iacovidou, E., Velis, C. A., & Atseyinku, M. (2018). Post-consumer plastic packaging waste in England: Assessing the yield of multiple collection-recycling schemes. *Waste Management*. https://doi.org/10.1016/j.wasman.2018.02.009

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2008.0311

Institute for European Environmental policy (2017). EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging. Available online: file:///C:/Users/utente/Downloads/EPR%20in%20the%20EU%20Plastics%20Strategy.pdf

ISPRA (2019). Rapporto rifiuti urbani. Edizione 2019. Available online: http://www.isprambiente.gov.it/files2019/pubblicazioni/rapporti/RapportoRifiutiUrbani_VersioneIntegralen313_2019_agg17_12_2019.pdf

Jacob, K., Binder, M., & Wieczorek, A. (2004). *Proceedings of the 2002 Berlin Conference on the Human Dimensions of Global Environmental Change "Knowledge for the Sustainability* Transition. The Challenge for Social Science''." FFU report 03–2004.

Kang, H. Y., & Schoenung, J. M. (2005). Electronic waste recycling: A review of U.S. infrastructure and technology options. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2005.06.001

Lange, J., & Wyser, Y. (2003). Recent Innovations in Barrier Technologies for Plastic Packaging - A Review. *Packaging Technology and Science*. https://doi.org/10.1002/pts.621

Lazarevic, D., Aoustin, E., Buclet, N., & Brandt, N. (2010). Plastic waste management in the context of a European recycling society: Comparing results and uncertainties in a life cycle perspective. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2010.09.014

Le Blevennec K., Jepsen D., Rödig L., Vanderreydt J., Wirth O. (2019). For better not worse: applying eco-design principles to plastics in the circular economy. Available online: https://ecostandard.org/wp-content/uploads/2019/06/APPLYING-ECODESIGN-PRINCIPLES-TO-PLASTICS.pdf

Lee, S. G., & Xu, X. (2005). Design for the environment: Life cycle assessment and sustainable packaging issues. *International Journal of Environmental Technology and Management*. https://doi.org/10.1504/IJETM.2005.006505

Legambiente (2019). Ecomafia 2019. Le storie e i numeri della criminalità ambientale in Italia

Lewandowski, M. (2016). Designing the business models for circular economy-towards the conceptual framework. *Sustainability (Switzerland)*. https://doi.org/10.3390/su8010043

Matsumoto, M., Yang, S., Martinsen, K., & Kainuma, Y. (2016). Trends and research challenges in remanufacturing. International Journal of Precision Engineering and Manufacturing - Green Technology. https://doi.org/10.1007/s40684-016-0016-4

Nakajima, N. (2000). A vision of industrial ecology: State-of-the-art practices for a circular and service-based economy. *Bulletin of Science, Technology and Society*. https://doi.org/10.1177/027046760002000107

Niero, M., & Olsen, S. I. (2016). Circular economy: To be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2016.06.023

OECD (2014). Waste Management Service. Available online: http://www.oecd.org/daf/competition/Waste-management-services-2013.pdf

Paletta, A., Leal Filho, W., Balogun, A.-L., Foschi, E., & Bonoli, A. (2019). Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.118149

Perugini, F., Mastellone, M. L., & Arena, U. (2005). A life cycle assessment of mechanical and feedstock recycling options for management of plastic packaging wastes. *Environmental Progress*. https://doi.org/10.1002/ep.10078

Pilz, H., Fehringer, R., & Brandt, B. (2010). The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe, Summary Report.

Pivnenko, K., Eriksen, M. K., Martín-Fernández, J. A., Eriksson, E., & Astrup, T. F. (2016). Recycling of plastic waste: Presence of phthalates in plastics from households and industry. Waste Management. https://doi.org/10.1016/j.wasman.2016.05.014

PlasticsEurope (2017). Plastics – the Facts 2017. Available online: https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

PlasticsEurope (2018). Plastics – the facts 2018. Available online: https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

PlasticsEurope (2019). Plastics – the facts 2019. Available online: https://www.plasticseurope.org/en/resources/publications/1804-plastics-facts-2019

PlasticsRecyclersEurope (2015). Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment. Available online: https://www.plasticsrecyclers.eu/sites/default/files/BIO_Deloitte_PRE_Plastics%20Recycling%20Impact_Assesment_Final%20Report.pdf

Polymer Comply Europe (2018). The Usage of Recycled Plastics Materials by Plastics Converters in Europe. A qualitative European industry survey.

Robinson, J. B. (1990). Futures under glass. A recipe for people who hate to predict. *Futures*. https://doi.org/10.1016/0016-3287(90)90018-D

Troitsch, J. (1990). International Plastics Flammability Handbook. Hanser Publishers, Munich.

Vergragt, P., & van der Wel, M. (1998). Backcasting: An Example of Sustainable Washing. In *Sustainable Strategies for Industry*.

Villanueva, A., Eder, P. (2014). End-of-Waste criteria for waste plastic for conversion. Technical proposal. European Union, Luxembourg. Report EUR 26843 EN. Available online: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/end-waste-criteria-waste-plastic-conversion-technical-proposals

– Chapter 8

Bras, B., & McIntosh, M. W. (1999). Product, process, and organizational design for remanufacture - An overview of research. Robotics and Computer-Integrated Manufacturing. https://doi.org/10.1016/S0736-5845(99)00021-6

Brezet, H., van Hemel, C,. (1997). Ecodesign: a promising approach to sustainable production and consumption.

British Plastics Federation (2018). Core principles. A summary of design by recyclability.

CONAI (2017). Linee guida per la facilitazione delle attività di riciclo degli imballaggi in materiale plastic. Available online: http://www.conai.org/wp-content/uploads/dlm_uploads/2017/07/Linee-Guida_Riciclo_Plastica.pdf

COREPLA (2014). Relazione sulla gestione 2014. Available online: http://www.corepla.it/documenti/55aea575-6a57-4c63-ad92-df2c2384d593/relazione+sulla+gestione+2014.pdf

COREPLA (2015). Relazione sulla gestione 2015. Available online: http://www.corepla.it/documenti/1af53d77-2634-4199-8714-e4e556270c9a/03_02_Relazione.pdf

COREPLA (2016). Relazione sulla gestione 2016. Available online: http://www.corepla.it/documenti/621248cb-892c-4351-bef3-4e55f4559919/03+Relazione+sulla+gestione+2016.pdf

COREPLA (2017). Relazione sulla gestione 2017. Available online: COREPLA (2016). Relazione sulla gestione 2016. Available online: http://www.corepla.it/documenti/621248cb-892c-4351-bef3-4e55f4559919/03+Relazione+sulla+gestione+2016.pdf

COREPLA (2018). Relazione sulla gestione 2018. Available online: http://www.corepla.it/documenti/c3cc963b-c446-46c3-809b-e17e487f8e2d/RELAZIONE+SULLA+GESTIONE+2018.pdf

Crippa, M., De Wilde, B., Koopmans, R., Leyssens, J., Muncke, J., Ritschkoff A-C., Van Doorsselaer, K., Velis, C. & Wagner, M. A (2019). Circular economy for plastics – Insights from research and innovation to inform policy and funding decisions, European Commission, Brussels, Belgium

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental Protection*. https://doi.org/10.4236/jep.2015.610096

Di Maio, F., Rem, P. C., Baldé, K., & Polder, M. (2017). Measuring resource efficiency and circular economy: A market value approach. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2017.02.009

Ellen MacArthur Foundation (2015). *Circularity Indicators, An Approach to Measuring Circularity, Methodology*. Available online: https://www.ellenmacarthurfoundation.org/assets/downloads/insight/Circularity-Indicators_Methodology_May2015.pdf

European Commission (2018). A European Strategy for plastics in a circular economy. Available online: https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf

European Commission (2019e). Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Implementation of the Circular Economy Action Plan. Available online: https://ec.europa.eu/commission/sites/beta-political/files/report_implementation_circular_economy_action_plan.pdf

EUROSTAT (2018). Circular material use rate. 2018 edition. Available online: https://ec.europa.eu/eurostat/documents/3859598/9407565/KS-FT-18-009-EN-N.pdf/b8efd42b-b1b8-41ea-aaa0-45e127ad2e3f

Evans J., Bocken N. (2017). *The Circular Economy Toolkit*. Available online: http://circulareconomytoolkit.org/

Fondazione Per lo sviluppo sostenibile (2019). L'Italia del Riciclo 2019. Available online: https://www.fondazionesvilupposostenibile.org/wp-content/uploads/dlm_uploads/L%E2%80%99Italia-del-Riciclo-2019.pdf

Griffiths P., Cayzer S. (2016). *Design of indicators for measuring product performance in the circular economy*; 2016. In proceeding of the 3rd International Conference on Sustainable Design and Manufacturing; Springer Science and Business Media Deutschland GmbH: pp. 307–321; Berlin, Germany.

Hahladakis, J. N., & Iacovidou, E. (2018). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2018.02.330

Hahladakis, J. N., Purnell, P., Iacovidou, E., Velis, C. A., & Atseyinku, M. (2018). Post-consumer plastic packaging waste in England: Assessing the yield of multiple collection-recycling schemes. Waste Management. https://doi.org/10.1016/j.wasman.2018.02.009

Hahladakis, J. N., & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials*. https://doi.org/10.1016/j.jhazmat.2019.120887

Holt, R., & Barnes, C. (2010). Towards an integrated approach to "design for X": An agenda for decision-based DFX research. Research in Engineering Design. https://doi.org/10.1007/s00163-009-0081-6

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2008.0311

Iacovidou, E., Millward-Hopkins, J., Busch, J., Purnell, P., Velis, C. A., Hahladakis, J. N., … Brown, A. (2017). A pathway to circular economy: Developing a conceptual framework for complex value assessment of resources recovered from waste. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.09.002

Institute for European Environmental policy (2017) . EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging. Available online: file:///C:/Users/utente/Downloads/EPR%20in%20the%20EU%20Plastics%20Strategy.pdf

Le Blevennec K., Jepsen D., Rödig L., Vanderreydt J., Wirth O. (2019). For better not worse: applying eco-design principles to plastics in the circular economy Available online: https://ecostandard.org/wp-content/uploads/2019/06/APPLYING-ECODESIGN-PRINCIPLES-TO-PLASTICS.pdf

Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.12552

OECD (2018). Improving Markets for Recycled Plastics. Trends, Prospects and Policy Responses. Available online: https://read.oecd-ilibrary.org/environment/improving-markets-for-recycled-plastics_9789264301016-en#page1

Pajula, T., Behm, K., Vatanen, S., & Saarivuori, E. (2017). Managing the life cycle to reduce environmental impacts. In *Dynamics of Long-Life Assets: From Technology Adaptation to Upgrading the Business Model*. https://doi.org/10.1007/978-3-319-45438-2_6

Rem, P. C., Olsen, S., Welink, J. H., & Fraunholcz, N. (2009). Carbon dioxide emission associated with the production of plastics - A comparison of production from crude oil and recycling for the Dutch case. In *Environmental Engineering and Management Journal*. https://doi.org/10.30638/eemj.2009.142

Shonfield, P. (2008). LCA of Management Options for Mixed Waste Plastics. Waste resource action programme WRAP. https://doi.org/1-81105-397-0

Tukker, A., Eder (IPTS, P., Charter, M., Haag, E., Vercalsteren, A., & Wiedmann, T. (2001). Eco-design: The State of Implementation in Europe – Conclusions of a State of the Art Study for IPTS. The Journal of Sustainable Product Design. https://doi.org/10.1023/A:1020564820675

UNI (2005). UNI EN 13428:2005. Requisiti specifici per la fabbricazione e la composizione - Prevenzione per riduzione alla fonte.

Verghese, K., Lewis H. (2007) Environmental innovation in industrial packaging: a supply chain approach. *International Journal of Production Research,* 45:18-19, 4381-4401, DOI: 10.1080/00207540701450211

WRAP (2006). Choosing the right recycling collection system. Available online: https://www.wrap.org.uk/sites/files/wrap/Choosing%20the%20right%20recycling%20collection%20system.pdf

WRAP (2011). Development of NIR Detectable Black Plastic Packaging. Available online: http://www.wrap.org.uk/sites/files/wrap/Recyclability%20of%20black%20plastic%20packaging.pdf

WRAP (2013). Design of rigid plastic packaging for recycling. Available online: http://www.wrap.org.uk/sites/files/wrap/Guidance%20Document%20%20Design%20of%20Rigid%20Plastic%20Packaging%20for%20Recycling.pdf

─ Chapter 9

Aras, G., Crowther, D. (2009). Making sustainable development sustainable. Management Decision.

Barra, R., & González, P. (2018). Sustainable chemistry challenges from a developing country perspective: Education, plastic pollution, and beyond. Current Opinion in Green and Sustainable Chemistry. https://doi.org/10.1016/j.cogsc.2017.12.001

Ellen MacArthur Foundation (2017). New plastics economy. Catalysing action. Available online: https://www.ellenmacarthurfoundation.org/assets/downloads/New-Plastics-Economy_Catalysing-Action_13-1-17.pdf Foschi, E., Bonoli. A. (2019). The Commitment of Packaging Industry in the Framework of the European Strategy for Plastics in a Circular Economy. Administrative Science Journal. doi:10.3390/admsci9010018

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … Law, K. L. (2015). *The ocean. Science*, 347, 768–771. *Science*. https://doi.org/10.1126/science.1260352

Paletta, A., Leal Filho, W., Balogun, A.-L., Foschi, E., & Bonoli, A. (2019). Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.118149

APPENDIX

Appendix n. 1 – LIST OF CONVERTERS (PLASTIC PACKAGING INDUSTRY) IN EMILIA ROMAGNA REGION

ID	Name	City	Province
1	**ILIP S.R.L.**	Bologna	BO
2	**INFIA S.R.L.**	Bertinoro	FC
3	**SOCIETA' GENERALE PER L'IMBALLAGGIO S.P.A. (NES.P.A.K S.P.A.)**	Massa Lombarda	RA
4	**COOPBOX GROUP S.P.A.**	Bibbiano	RE
5	**SAICA FLEX ITALIA S.P.A.**	Meldola	FC
6	**SARONG S.P.A (SARONG S.P.A.)**	Reggiolo	RE
7	**ISI PLAST S.P.A.**	Correggio	RE
8	**PLASTISAVIO S.P.A.**	Mercato Saraceno	FC
9	**LAVORAZIONE PLASTICA S.R.L.**	Granarolo dell'Emilia	BO
10	**CASTAGNA UNIVEL S.P.A.**	Piacenza	PC
11	**GAMMA PACK S.P.A.**	Langhirano	PR
12	**TECNOFORM - S.R.L.**	Colorno	PR
13	**RENATO LUSA S.R.L.**	Massa Lombarda	RA
14	**ENCAPLAST S.P.A.**	Mirandola	MO
15	**RPC SUPERFOS ITALY S.R.L.**	Castel Guelfo di Bologna	BO
16	**WIPAK BORDI S.R.L.**	Caorso	PC
17	**FILCA UNIVEL SOCIETA' A RESPONSABILITA' LIMITATA ENUNCIABILE ANCHE FILCA UNIVEL S.R.L.**	Piacenza	PC
18	**SELIP S.P.A.**	Fontanellato	PR
19	**TECNOPACK UNIVEL S.R.L.**	Piacenza	PC
20	**TERMOPLASTICA SGHEDONI S.P.A. (TPS S.P.A.)**	Modena	MO
21	**GAM PLAST S.P.A.**	Castellarano	RE
22	**LELIPLAST S.R.L.**	Forlì	FC
23	**BLOWPACK S.R.L.**	Formigine	MO
24	**RAVIPLAST SOC. COOP.**	Ravenna	RA
25	**MAXIMCOM S.R.L.**	Ferrara	FE
26	**CONFEZIONI PLAX S.R.L.**	Savignano sul Rubicone	MO
27	**REALCART S.R.L.**	Parma	PR
28	**SILTE S.R.L.**	Budrio	BO
29	**VEXEL S.R.L.**	Parma	PR
30	**CAMPANINI UGO S.R.L.**	Pieve di Cento	FE
31	**REDMARK S.R.L.**	Carpi	MO
32	**SPILA - S.R.L.**	Spilamberto	MO
33	**PLAST EMILIA S.R.L.**	Bagnolo in Piano	RE
34	**PLASTILENE S.R.L.**	Rio Saliceto	RE
35	**ALVAPACK S.R.L.**	Bologna	BO

36	**KUKU INTERNATIONAL PACKAGING S.R.L.**	Crevalcore	BO
37	**MATTEIPLAST S.R.L.**	San Lazzaro di Savena	BO
38	**POLIRAMA ITALIA S.R.L.**	Rivergaro	PC
39	**S.I.M.M. IMBALLAGGI S.R.L.**	Bologna	BO
40	**GIGLIOLI FABRIZIO S.R.L.**	Novi di Modena	MO
41	**PLASTIGROUP S.R.L.**	Reggio nell'Emilia	RE
42	**NORD OVEST PACKAGING S.R.L.**	Calendasco	PC
43	**LOGICAS S.R.L.**	Gatteo	FC
44	**FIORINI IMBALLAGGI S.R.L.**	Forlì	FC
45	**CELLORAMA S.R.L.**	Bertinoro	FC
46	**PROCTER S.R.L.**	Castel Guelfo di Bologna	BO
47	**POLIFLEX S.R.L.**	Carpi	MO
48	**PLASTEC ITALIA S.R.L.**	Ravenna	RA
49	**ROSSI IMBALLAGGI S.R.L.**	Parma	PR
50	**GI ERRE PLASTICA - S.R.L. (GI ERRE S.R.L.)**	Calderara di Reno	BO
51	**VEXEL 74 S.R.L.**	Parma	PR
52	**PLASTOTUBE S.R.L.**	Noceto	PR
53	**NUOVA GILPLAST S.R.L.**	Carpi	MO
54	**RECOS S.R.L.**	Poviglio	RE
55	**CONSTANTIA SAN PROSPERO S.R.L.**	San Prospero	MO
56	**M.R. - S.R.L.**	Langhirano	MO
57	**TANKMASTERS MURATORI S.R.L.**	Spilamberto	MO
58	**KARTONPLASTITALIA S.R.L.**	Reggiolo	RE
59	**NALDI ECOLOGIA S.R.L.**	Imola	BO
60	**DEEP BLUE S.R.L.**	Parma	PR
61	**LANDINI S.R.L.**	Sassuolo	MO
62	**LAVORAZIONE IMBALLAGGI FLESSIBILI S.R.L. (LIF S.R.L.)**	Castel San Giovanni	PC
63	**LAVORAZIONE ITALIANA SCATOLAME TRAS.P.A.RENTE (L.I.S.T. - S.R.L.)**	Carpi	MO
64	**BACS S.R.L.**	Podenzano	PC
65	**POGGI PACK S.R.L.**	Savignano sul Rubicone	FC
66	**PHILPLAST S.R.L.**	Rio Saliceto	RE
67	**EUROFORM S.R.L.**	Reggio nell'Emilia	RE
68	**RESMAV MEDICAL PACKAGING S.R.L. (RESMAV S.R.L.)**	Modena	MO
69	**TECNO FILM S.R.L.**	Parma	PR
70	**CELLOTECNICA S.R.L.**	San Lazzaro di Savena	BO
71	**COMINEL S.R.L.**	Conselice	RA
72	**R.S. PLAST S.R.L.**	Formigine	MO
73	**3 P S.R.L.**	Forlì	FC
74	**IPACK-IMOLA S.R.L.**	Imola	BO
75	**CUT SERVICE ROMAGNA S.A.S.**	Riccione	RN
76	**PLASTI-SHOP S.R.L.**	Cesena	FC
77	**PLASTIC PACK S.R.L.**	Reggio nell'Emilia	RE
78	**ALBANOVA S.R.L.**	Spilamberto	MO

79	**ECORECYCLING S.R.L.**	Correggio	RE
80	**PLASTOUNO S.R.L.**	Imola	BO
81	**PROGENY WIPC S.R.L.**	Reggio nell'Emilia	RE
82	**HUNTSMAN PATRICA S.R.L.**	Castelfranco Emilia	MO
83	**HELESI ITALIA S.R.L.**	Modena	MO
84	**ACUMEN S.R.L.**	Bologna	BO
85	**PLASTAL S.R.L.**	Sant'Ilario d'Enza	RE
86	**ULTRASAC S.R.L.**	Sant'Ilario d'Enza	RE
87	**CRISIT S.R.L.**	Sant'Ilario d'Enza	RE
88	**SFERIBIT S.R.L.**	Parma	PR
89	**ALPLAST S.R.L.**	Parma	PR
90	**TECNOES.P.A.NSI S.R.L.S.**	San Giorgio di Piano	BO

Appendix n. 2 – LIST OR WASTE PLANTS (R3) IN EMILIA ROMAGNA REGION

ID	Name	City	Province	R3 (t)
1	**A.M.P. RECYCLING S.R.L.**	Ferrara	FE	15.198
2	**ALAN PAGANI**	Monticelli d'Ongina	PC	8
3	**ATLAS S.R.L.**	Noceto	PR	410
4	**B.R. PLAST S.R.L.**	Mercato Saraceno	FC	10
5	**BALBONI OMERO S.R.L.**	Sant'Agostino	FE	648
6	**BANDINI-CASAMENTI S.R.L.**	Forlì	FC	4.273
7	**BARBIERI FEDERICO E FIGLI S.R.L.**	Mesola	FE	502
8	**BERTANI S.R.L.**	Reggio Emilia	RE	2
9	**BO-LINK SCRL**	Minerbio	BO	204
10	**BRAGHIERI PLASTIC S.R.L.**	Sarmato	PC	1.820
11	**C.B.R.C. S.R.L.**	Bologna	BO	86
12	**CA.RE. S.R.L.**	Carpi	MO	9.758
13	**CHIAPPELLI S.R.L.**	Savignano Sul Panaro	MO	121
14	**COMISOL DI CORTESI GIANANDREA E C. S.N.C.**	Faenza	RA	2
15	**ECOCHIMICA S.R.L.**	Lugo	RA	111
16	**ECOREP S.R.L.**	Castello d'Argile	BO	370
17	**ECOWELL SYSSTEM S.R.L.**	Boretto	RE	872
18	**F.LLI LONGO INDUSTRIALE S.R.L.**	Rio Saliceto	RE	642
19	**F.P. PLAST S.R.L.**	Scandiano	RE	6
20	**FORPLAST S.R.L.**	Castell'Arquato	PC	2742
21	**FUSTAMERIA ALBERTAZZI S.N.C.**	Castel Guelfo di Bologna	BO	18
22	**G.M. PLAST DI GIANNI MAGRI**	Argelato	BO	1
23	**H.E.R.S.S.R.L. HIGH ENERGY RECYCLING SYSTEM**	Bondeno	FE	42
24	**HERAMBIENTE_S.P.A. IM_IMP_REC_MORDANO**	Sesto Imolese	BO	4
25	**HERAMBIENTE_S.P.A. RA_IMP_REC_VOLTANA**	Lugo	RA	10.043
26	**IL SOLCO COOP. SOCIALE A R.L. ONLUS**	Savignano Sul Rubicone	FC	1.535
27	**MAGNANI GUERRINO & C S.N.C.**	Gambettola	FC	1
28	**ME YU MA PLAST S.R.L.**	Malalbergo	BO	753
29	**MELOREC S.N.C. DI MELONI ALBERTO E C.**	Bondeno	FE	335
30	**METALFERRO S.R.L.**	Modena	MO	11

ID	Name	City	Province	R3 (t)
31	**MIRAPLASTIK S.R.L.**	Mirandola	MO	98
32	**N.E.S. S.R.L.**	Poggio Torriana	RN	665
33	**NEVICOLOR S.P.A.**	Luzzara	RE	40
34	**OPPIMITTI COSTRUZIONI S.R.L.**	Borgo Val di Taro	PR	1.666
35	**PAGANI ALAN S.R.L. SOCIETA' UNIPERSONALE**	Monticelli d'Ongina	PC	87
36	**PENTA PLAST DI SATANASSI ARNALDO & C. SNC**	Sant'Agata Feltria	RN	56
37	**PLASTISAVIO S.P.A.**	Mercato Saraceno	FC	543
38	**POLAR S.R.L.**	Ferrara	FE	48
39	**POLITEC PRODUZIONE POLIMERI SPECIALI S.R.L.**	Castello d'Argile	BO	378
40	**RIMPLASTIC S.R.L.**	Conselice	RA	23
41	**ROSSI ADRIANO DI ROSSI FABRIZIO**	Polesine Parmense	PR	761
42	**S.A.BA.R. S.P.A.**	Cadelbosco di Sopra	RE	60
43	**SAIDA S.R.L. INDUSTRIA VETRARIA**	Longiano	FC	42
44	**SALTARELLI S.N.C. DI SALTARELLI STEFANO & C.**	Crevalcore	BO	219
45	**SAMI AUTODEMOLIZIONE DI SAMI MASSIMILIANO & C S.N.C.**	Cesenatico	FC	8
46	**SOCIETA' EUROPEA RIGENERAZIONE S.R.L. (SER S.R.L.)**	Fidenza	PR	15.822
47	**STARPLASTICK S.R.L.**	Parma	PR	5.748
48	**UNIRECUPERI S.R.L.**	Ferrara	FE	2070
49	**VAL-PLAST S.R.L.**	Bondeno	FE	209
50	**VINYLOOP FERRARA S.P.A.**	Ferrara	FE	4.264
51	**WHITE FOX S.R.L.**	Pontenure	PC	315
52	**ZOFFOLI METALLI S.R.L.**	Copparo	FE	117

Appendix n.3 – LIST OR WASTE PLANTS (R4) IN EMILIA ROMAGNA REGION

ID	Name	City	Province	R4 (t)
1	**DEVOTI RECUPERI ECOLOGIA S.N.C.**	Cortemaggiore	PC	5
2	**PADANA COMMERCIO S.R.L.**	Cento	FE	61
3	**TRAS-PRESS AMBIENTE S.R.L.**	Bagnara di Romagna	RA	25

Appendix n.4 – LIST OR WASTE PLANTS (R5) IN EMILIA ROMAGNA REGION

ID	Name	City	Province	R5 (t)
1	**AIRONE S.P.A. CONSORTILE**	Ravenna	RA	250
2	**ARGECO S.P.A.**	Argenta	FE	55.475
3	**ECOFELSINEA S.R.L.**	Bologna	BO	72
4	**F.G.S. DI GUIDI FERNANDO & C. S.R.L.**	Comacchio	FE	740
5	**HERAMBIENTE_S.P.A.-RA_CDR.PROD1.2,6.RA**	Ravenna	RA	742
6	**MONTI AMATO S.R.L.**	Ravenna	RA	88
7	**NIAL NIZZOLI S.R.L.**	Correggio	RE	7
8	**R.O.L. S.R.L.**	Forli'	FC	32
9	**RE.MA.IND. S.R.L.**	Mordano	BO	0
10	**TRAS-PRESS AMBIENTE S.R.L.**	Bagnara di Romagna	RA	92
11	**UNIRECUPERI S.R.L.**	Ferrara	FE	1.360

Appendix n.5 – LIST OR WASTE PLANTS (R12) IN EMILIA ROMAGNA REGION

ID	Name	City	Province	R12 (t)
1	**ALFAREC S.R.L.**	Pianoro	BO	64
2	**APPENNINO AMBIENTE S.R.L.**	San Benedetto Val di sambro	BO	731
3	**AREA IMPIANTI S.P.A.**	Jolanda di Savoia	FE	87
4	**ARTONI AUTODEMOLIZIONI S.R.L.**	Sorbolo Mezzani	PR	0
5	**BOLOGNA ECOLOGIA S.R.L.**	San Giorgio di Piano	BO	6
6	**CERPLAST S.R.L.**	Formigine	MO	8.340
7	**CONSORZIO LAMBERTINI**	Valsamoggia	BO	7
8	**DARIO PASQUALINI ROTTAMI DI MATTIA PASQUALINI**	Ferrara	FE	8
9	**DE PAAUW RECYCLING ITALIA S.R.L.**	Rio Saliceto	RE	15.177
10	**ECO PLAST S.R.L**	Modena	MO	4.420
11	**ECO.SER.**	Castenaso	BO	60
12	**FARO SERVICE S.R.L.**	Castel Maggiore	BO	1
13	**FERRARESI COMM.ROTTAMI S.R.L. SOC.UNIPERSONALE**	Copparo	FE	64
14	**GHEO SUOLO E AMBIENTE S.R.L.**	Brescello	RE	18
15	**GHIRARDI S.R.L. SOCIO UNICO**	Parma	PR	1.214
16	**HERAMBIENTE_S.P.A.-BO_IMP_REC_GRANAROLO**	Granarolo Dell'Emilia	BO	738
17	**HERAMBIENTE_S.P.A.-FE_IMP_REC_FERRARA**	Ferrara	FE	6.592
18	**HERAMBIENTE_S.P.A.-IM_IMP_REC_MORDANO**	Sesto Imolese	BO	1.904
19	**HERAMBIENTE_S.P.A.-MO_IMP_REC_MODENA**	Modena	MO	1.7820
20	**HERAMBIENTE_S.P.A.-RN_IMP_REC_CORIANO**	Coriano	RN	1.6749
21	**IDEALSERVICE SOC. COOP.**	Cadelbosco di Sopra	RE	2.2118
22	**IL SOLCO COOP. SOCIALE A R.L. ONLUS**	Savignano Sul Rubicone	FC	6.946
23	**INERTI CAVOZZA S.R.L.**	Sorbolo Mezzani	PR	1.825
24	**ITALMETALLI S.R.L.**	Crespellano	BO	12
25	**L.E.M.I.R. S.R.L.**	Savignano Sul Panaro	MO	25
26	**LA CART**	Rimini	RN	43
27	**LONGAGNANI ECOLOGIA S.R.L.**	Modena	MO	215
28	**MONTIECO S.R.L.**	Anzola Dell'Emilia	BO	8
29	**N.E.S. S.R.L.**	Poggio Torriana	RN	11

ID	Name	City	Province	R12 (t)
30	**OPPIMITTI COSTRUZIONI S.R.L. (CENTRO DI RECUPERO)**	Borgo Val di Taro	PR	1.177
31	**OPPIMITTI ENERGY S.R.L.**	Bedonia	PR	3.808
32	**PASSERINI RECUPERI S.R.L.**	Cento	FE	31
33	**PETRA POLIMERI**	Ferrara	FE	6.019
34	**RECTER S.R.L.**	Imola	BO	357
35	**REGGIANA AMBIENTE E RECUPERI S.R.L.**	Bibbiano	RE	1.409
36	**RIMONDI PAOLO S.R.L.**	Bologna	BO	83
37	**S.A.BA.R. S.P.A.**	Cadelbosco di Sopra	RE	4.124
38	**SOGLIANO AMBIENTE S.P.A. - CERNITA**	Sogliano Al Rubicone	FC	3.343
39	**SPECIALTRASPORTI S.R.L.**	Sala Bolognese	BO	793
40	**TRAS-PRESS AMBIENTE S.R.L.**	Bagnara di Romagna	RA	3.587
41	**TRS ECOLOGIA S.R.L. (IMPIANTO)**	San Pietro in Cerro	PC	134
42	**WHITE FOX S.R.L.**	Pontenure	PC	5.835

Appendix n.6 – DESCRIPTION OF ACTIVITY A

ACTIVITY A		
Type of activity	Survey	
Objective	Quantitative (part I) and qualitative (part II) analysis about the usage of recycled plastics	
Reference year	2012-2018	
Type of stakehoders	Plastic Converters	
Contents	Survey	
	2012	2018
	a. Which plastics resins do you use?	a. Have you introduced/increased the use of recycled plastics?
	b. Where do you supply that plastic resins?	b. If yes, how much?
	c. Do you use recycled plastics?	c. Have you introduced/increased the use of recycled plastics in your process?
	d. If yes, how much?	d. If yes, how much?
	e. What technological innovation have you intorduced in your process to managed recycled plastics?	e. What technological innovation have you introduced in your process to managed recycled plastics?
	f. Which barriers have you met?	f. Which barriers have you met?
	If no, why?	If no, why?
Number of stakeholders	364	
Number of active stakeholders	41	35
List of active stakeholders	Oremplast S.R.L. Ghepi S.R.L. CSPLAST S.R.L. Cantelli E Poli S.R.L. Termoplastica Sghedoni S.P.A. Alfa Plastic S.R.L. C.E.G. S.R.L. I.L.P.A. S.R.L. Emilplastica S.R.L. Cattini S.R.L. Wegaplast S.p.A. Blowpack S.R.L. Termoplasica Nevianese S.R.L. Tecnostefi S.R.L. Proni S.R.L. Tecnoform S.P.A. Ecochimica S.R.L. Plastital S.R.L. Inerti Cavozza S.R.L. Lapi Plast S.R.L. Plastipadana System S.R.L. Stargomma S.R.L. A-Z GOMMA RICAMBI S.R.L. TPV Compound S.R.L. Romagna plastic S.R.L. Bertolini Divisione Elastomeri S.R.L. Resin Edil Modenese S.R.L. Modena nastri S.R.L. Plastekno S.R.L. Transfer oil S.P.A. ILMAP S.R.L. C.G.M. S.P.A. A.E.M. S.R.L. Effegidi international S.P.A. Gecam S.R.L. ILPO S.P.A. MAV S.R.L. Poplast S.N.C. Soplast S.R.L. Testiplast S.R.L. Plastomec S.R.L.	A-Z GOMMA RICAMBI S.R.L. TPV Compound S.R.L. Romagna plastic S.R.L. Bertolini Divisione Elastomeri S.R.L. Plastekno S.R.L. Transfer oil S.P.A. ILMAP S.R.L. C.G.M. S.P.A. A.E.M. S.R.L. Effegidi international S.P.A. Gecam S.R.L. ILPO S.P.A. MAV S.R.L. Soplast Emiliana S.R.L. Plastomec S.R.L. Tecnostefi S.R.L. Ghepi S.R.L. C.E.G. S.R.L. I.L.P.A. S.R.L. Emilplastica S.R.L. Wegaplast S.P.A. Blowpack S.R.L. Termoplastica Nevianese S.R.L. Proni S.R.L. Tecnoform S.R.L. Ecochimica S.R.L. Plastital S.R.L. Inerti Cavozza S.R.L. Lapi Plast S.R.L. Plasticpadana System S.R.L. Termoplastica Sghedoni S.P.A. Alfa Plastic S.R.L.

Appendix n.7 – DESCRIPTION OF ACTIVITY B

ACTIVITY B	
Type of activity	Questionnaire
Objective	Quantitative (part I) and qualitative (part II) analysis on the production of recycled plastics
Reference year	2017
Type of stakehoders	Plastic waste Recyclers and Sorters
Contents	Questionnaire
	a. General information about the company and the plant
	b. Amount of input materials by EWC and provenience - 2017
	c. Amount of waste stocked - 2017
	d. Type of activity (sorting, recycling, other) and machinery
	e. Type of recycling process (mechanical, chemical)
	f. Type of machines
	f. Amount of output materials (waste and secondary plastics) by polymer type and destination - 2017
Number of stakeholders	98
Number of active stakeholders	19
List of active stakehoders	BALBONI OMERO S.R.L. ALFAREC S.R.L. AMP RECYCLING S.R.L. BANDINI-CASAMENTI S.R.L. BO-LINK SOC. CONSORTILE A R.L. Comisol S.R.L. GHEO SUOLO E AMBIENTE S.R.L. HERAmbiente S.P.A. – Coriano HERAmbiente S.P.A. - Ferrara HERAmbiente S.P.A. – Granarolo dell'Emilia HERAmbiente S.P.A. - Modena HERAmbiente S.P.A. - Mordano IL SOLCO SOC. COOP. LONGAGNANI ECOLOGIA S.R.L. MONTI AMATO S.R.L. PETRA POLIMERI S.R.L. S.E.R. S.R.L. STARPLASTICK S.R.L. SOGLIANO AMBIENTE S.P.A.

Appendix n.8 – DESCRIPTION OF ACTIVITY C

ACTIVITY C	
Type of activity	Semi-structured interview
Objective	Strategic policy setting up and planning
Reference year	2018
Type of stakehoders	Policy makers and supporting public organizations and agencies
Contents	Interview
	a. Current regional supporting policy and measures for plastics recycling and recyclability
	b. Legislative barriers
	c. Administrative barriers
	d. Financial barriers
	e. Needs
Number of stakeholders	4
Number of active stakeholders	4
List of active stakehoders	DIRECTORATE GENERAL ENVIRONMENT, EMILIA ROMAGNA REGION DIRECTORATE GENERAL ECONOMY, EMILIA ROMAGNA REGION ARPAE COREPLA

Appendix n.9 – DESCRIPTION OF ACTIVITY D

ACTIVITY D	
Type of activity	Match-making workshop
Objective	Meso-level barriers analysis and problem orientation to foster plastic sustainability (prevention at first, recycling then)
Reference year	2019
Type of stakehoders	Stakeholders involved in the plastic (packaging) value chain
Contents	Value creation space
	a. Strategies to implement sustainability (prevention as well as recycling)
	b. Training activities to imprve knowledge on circular economy
	c. Supporting tools for stakeholders working in the plastics industry
	d. Networking
Number of stakeholders	15
Number of active stakeholders	15
List of active stakeholders	DIRECTORATE GENERAL ENVIRONMENT, EMILIA ROMAGNA REGION DIRECTORATE GENERAL ECONOMY, EMILIA ROMAGNA REGION NATIONAL CONFEDERATION FOR CRAFT AND SMALL MEDIUM ENTERPRISES (CNA) NATIONAL COOPERATIVE SOCIETY FOR RESTORATION/CATERING (CIRFOOD) ENERGY AND ENVIRONMENT LAB PIACENZA (LEAP-POLIMI) UNIVERSITY OF BOLOGNA ANCI ENEA HERA AMBIENTE S.P.A. AIMAG S.P.A. ILPA S.P.A. AMADORI S.P.A. TETRAPACK S.P.A. ASCOM S.P.A. ARTI GRAFICHE REGGIANI S.R.L.