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CRITICAL BARRIERS FOR PLASTIC RECYCLING. A CC CASE-STUDY IN TURIN*

Nicole Mariotti[1], Grazia Sveva Ascione[2], Dario Cottafava[3], Federico Cuomo[4]**

[1]University of Turin, Department of Chemistry, Via Pietro Giuria 7, 10125, Turin, Italy
[2]University of Turin, Department of Economics and Statistics "Cognetti de Martiis", Lungo Dora Siena 100/A, 10100, Turin, Italy
[3]University of Turin, Department of Physics, Via Pietro Giuria 1, 10100, Turin, Italy
[4]University of Turin, Department of Culture, Politics and Society, Lungo Dora Siena 100/A, 10100, Turin, Italy

Abstract

Waste accumulation is one of the most discussed environmental issues which is jeopardizing our planet from an environmental, economic and social point of view. In this context, plastic plays a pivotal role, because its accumulation and persistence is becoming a matter of great concern. In 2017, 43% of plastic packaging is recycled.. In order to understand the barriers and the criticisms which hamper the development of a more efficient recycling pathway for plastics, one of the most important material recovery plants of Turin has been selected as case of study. The plants belongs to Amiat, the multi-utility working in waste collection on the behalf of Turin Municipality. This plant can treat up to 66 ktons/year of plastic packaging. Its function is to pre-select the materials coming from the separate collection, in order to guarantee the necessary level of quality to allow the recycling process. In fact, pre-selection is required for different reasons: a non-efficient separation performed by the citizen, as well as administrative and legal constraints on plastics treatment, such as recycling plastic packaging only. Hence, this work is willing to identify the key-actors involved in the plastic recycling process as well as to analyse the role of the selected plant using a case study methodology, assessing the key barriers and suggesting possible solutions for future scenarios of plastics recycling.

Keywords: circular economy, plastic market, plastic recycling

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** Corresponding author: e-mail: nicole.mariotti@unito.it

1. Introduction

From 1950 onwards, it is estimated that about 6’300 Mtons of primary and secondary plastic waste have been produced on the planet. Furthermore, it is estimated that 79% of plastic waste has been accumulated in landfill or discarded in the environment, whereas only 9% has been recycled (Geyer et al., 2017). Although public opinion has recently been affected by impactful media exposition, such as the dissemination of news and data about the island of plastics in the Pacific Ocean (Lebreton et al., 2018) called *Pacific Trash Vortex (Great Pacific garbage patch)*, environmental policies in developed countries are struggling to reach effective results. In the developed areas supposed to be keen on environmental awareness, such as Europe, policies to optimize and improve plastic recovery are unable to take off the ground (DESA, 2013). Thus, the awareness of the issue is not consistent with data about plastic recycling. For instance, European citizens declared themselves aware about the environmental impact of plastics, and concerned about the management of this kind of waste (Syberg et al., 2018). On the other hand, according to Eurostat Report (2018), each European citizen produces 31 kg of plastic packaging waste every year, which leads to a total of 15.8 Mtons in the European Union (EU). Nevertheless, in European countries, only 40% of plastic packaging is currently recycled (EC, 2015). In Italy, the amount of plastic packaging actually recycled is around 43% (PlasticsEurope, 2018). This dynamic is consistent with the continuous growth in the rate of separate collection, by now close to 55%, which led to the progressive increase of the plastic percentage transported to recovering and recycling centers (ISPRA, 2017).

In the City of Turin, the rate of separate collection is only around 45% and the quantity of plastic addressed to material recovery plants is constantly growing (Commune di Torino, 2018). The plant selected for this case-study stores and sorts the plastic waste coming from the separate collection of the City of Turin. It represents a preliminary step for plastics before going into the recycling process to guarantee suitable plastic waste for the recycling process.

The main objective of this work is to investigate the barriers for plastic recycling starting from the case-study of the selected plastics recovery plant in Turin. The analysis of the material and money flows, the study of plastic materials and the examination of the normative led to the identification of relevant key barriers which might hamper the already "complex" recycling process of plastics. In this research, we aim to identify whether the selected plant is necessary to guarantee an efficient recycling process or why it might not be in the next future.

The authors rebuilt the whole plastic recycling framework through the definition of plastics as polymeric materials (3.1) with their specific characteristics and the main categories for the recycling (3.2). The Italian situation (3.3), the stakeholder analysis and the plastic ecosystem are explained afterwards (3.4). Finally, the plant is analyzed (3.5) as well as an exploration of the relevant regulations including the birth of CONAI is done, providing the starting point for potential future scenarios (3.6).

2. Methodology

The methodology chosen is the case-study analysis. The choice of the plant is relevant because dynamics of CCs (*Centro Comprensoriale*-Plants of recovering materials) are not explored at all, because their value is often underestimated due to their small dimension. In fact, this research wants to analyze their role, considering their work of pre-selection is fundamental for the whole plastic recycling value chain. It is acknowledged that CCs are complex systems and it is worth investigating why they are necessary and whether they might not be in the next future. In order to reach this purpose, official documents of COREPLA are used, as well as information provided on COREPLA website.

3. Results and discussion

In this section, the definition of plastic is presented, in order to give clarity to the concepts involved. Then a quick excursus about different kinds of plastic recycling is proposed. Afterwards, the Italian packaging ecosystem is analyzed, identifying the most relevant actors involved, as well as the case study of the selected CC is taken into careful consideration, in terms of money and materials flow, highlighting pros and cons of the actual existing Italian plastic recycling network. Finally, the enactment of Ronchi Decree is discussed, explaining the reasons and the perspectives after the birth of CONAI.

3.1. Plastic: one definition for a plethora of materials

The International Union of Pure and Applied Chemistry defines plastic as a "*polymeric material that may contain other substances to improve performance and/or reduce costs*" (Vert et al., 2012). Actually, there are a plethora of different plastics whose our products are made of and there are codes (Table 1) to help the identification of the type of plastic in order to facilitate the recycling process according to international standards.

Table 1. Classification of plastics according to the International Standards (adapted from Wong, 2010)

Symbol	*Type of Plastics*	*Main Use*
1 PETE	Polyethylene Terephthalate (PET)	PET is used for containers for foods and liquid, soft drink bottles, fibers for clothing.
2 HDPE	High Density Polyethylene (HDPE)	HDPE is used for bottles, piping for water and sewer, milk jugs, detergent bottles, nursery pots, oil containers, snowboards, boats and chairs
3 V	Polyvinyl Chloride (PVC)	PVC (or vinyl) is common for products such as plumbing products, medical tubing, pressure pipes, electrical cable insulation, outdoor furniture, liquid detergent containers, etc.
4 LDPE	Low Density Polyethylene	This polyethylene is ductile and, thus, used for shopping bags, food containers, films or bags and stretch wrap
5 PP	Polypropylene (PP)	PP is a thermoplastic polymer and one of the worldwide most common used plastic. It is used for laboratory equipment, automotive parts, medical devices, etc.
6 PS	Polystyrene (PS)	PS is commonly used for yoghurt pots, foodservice containers, CD cases, envelope windows, video cassettes, appliance housings as televisions.
7 OTHER	Other types of plastics	Various usages.

3.2. Plastics recycling

Plastic recycling process can be mechanical or chemical: the former consists of the re-melting and the re-extrusion of the polymer. The latter one is the chemical break of the polymer in smaller molecules which can be re-used either to produce a new polymer or another material. In any case, each process requires resources, such as water, and energy: thus, the golden rule, i.e. the most efficient solution to the waste accumulation issue, it must always be the minimization of waste. It is relevant to know that plastics are divided in two main classes. Each class of plastics exhibits different properties and different behaviors towards the recycling processes. Plastics that are solid materials obtained through the melting and subsequent cooling of the polymer are called *thermoplastics.* The recycling of these plastics is easy enough: it is sufficient to heat and reshape these materials. It is important to highlight that repeated processing may alter the properties of the polymers. Plastics having their set properties and shapes obtained through the so-called crosslinking reactions are called *thermosetting plastics*. These plastics are more difficult to recycle because the heating process leads to their chemical degradation. There are four different classes of plastic recovering processes (Elias, 2003):

1. *Primary mechanical recycling*: uncontaminated plastic is directly recycled (usually for industrial waste);
2. *Secondary mechanical recycling*: post-consumer plastics are sorted and purified and then recycled;
3. *Chemical recycling*: plastics are broken into smaller molecules. In this way, it is possible to obtain the starting material, a new plastic or another different product;
4. *Incineration*: plastic is burnt. The released heat is used to produce energy.

Another kind of plastic disposal is composting: the material is broken through a biodegradation process into smaller molecules, carbon dioxide and water without the formation of toxic substances, within the time and with the conditions described by the regulation. In Italy, the characteristics for compostability are defined in the UNI EN 13432 (2002). Not all plastics can be recycled and the first step to correctly recycle in an efficient way is the proper separation of plastic waste from other materials. Each recycling process exhibits its own criticisms due to different reasons: citizens' awareness, technology readiness, economic feasibility, lack of policies. In Table 2 the criticisms, from a chemical point of view, for the different kind of disposal are listed (presented). From Table 2, it is possible to observe that there are some issues which need to be overcome yet. From a chemical point of view, it is important to consider the strategies adopted to have a good quality final material (conditions of the process), as well as the energy and the resources exploited in the recycling process.

It is relevant to notice that, when discussing about chemical recycling, materials, and not products, are taken into account. On the contrary, the Italian law, with the establishment of CONAI (2015), regulates the recycling of packaging; thus, it is based on products and not on materials. Indeed, in Italy, certain products made of recyclable materials are not collected only because they don't act as packaging. The in-use Italian normative is discussed in details in next sections. A sound idea to simplify the entire process might be to regulate the collection of all plastics based on material types instead of product types.

In this way, the rate of recyclable plastics could be improved as well as the separation between plastic and non-plastic materials could be easier both for citizens and for a plant as the case-study considered. In addition, chemistry must innovate materials at the first stage of production, i.e. when they are synthesized, to make them more recyclable and it must continue to study new processes to recycle the plastics that are not yet recycled and to make the already existent ones more efficient.

The re-design of materials with the purpose to make them easier to recycle and following a production process closer to the Green Chemistry Principles (Anastas and Warner, 1998) is, nowadays, one of the main challenges for a chemist. To sum up, it is worth highlighting that materials must satisfy a certain function, comply with the legislation and be economically viable at the same time.

Table 2. Plastic recycling processes: criticism and solutions

Plastic recycling process	***Criticisms***
MECHANICAL RECYCLING	Loss of qualities. Use of energy and resources. The presence of additives or mixed materials can jeopardize the recycling.
CHEMICAL RECYCLING	Difficult for some plastics to recover *selectively* the starting materials. Use of energy and resources. The presence of additives or mixed materials can jeopardize the recycling.
INCINERATION	The material cannot be re-used in the production cycle but energy is recovered. Life Cycle Assessments are necessary to evaluate which way is the most sustainable.
COMPOSTING	Misunderstanding of right collection rules by citizens. Lack of effective campaigns of information on key-terms as "biodegradable" and "compostable".

3.3. The Italian situation

In the last decade, every year around 2’200 ktons of plastic packaging are introduced by the Italian market (PlasticsEurope, 2018). The recycling system allows to recover 87.5% of post-consumer plastic packaging: 44.5 % was used to produce new raw material, while 43% was destined to energy recovery. According to PlasticsEurope (2018), from 2006 to 2016 the volumes for recycling increased by 46%, while energy recovery increased by 53% and landfill decreased by 49%.

The Italian plastic packaging supply chain is regulated, at national level, by a unique actor, COREPLA. COREPLA is the national consortium intended for collecting, recycling and recovering plastic packaging and it contributed to collect the 51% of plastic packaging in 2018. It collected 1’219’571 tons, whose 110’823 tons consisted of outer fraction, allowing to avoid the production of around 900 ktons of CO_2. The outer fraction, according to the Italian laws, is the part of waste coming from the separated collection, not homogeneous with the type of material collected (e.g.: glass in the paper bin). Generally, the outer fraction reduces the purity of the collected material, decreases its value and must be disposed of separately (ETRA, 2011). The Italian plastic packaging ecosystem is composed by several private and public stakeholders. The simplified material flow is depicted in Fig. 1.

The plastic packaging value chain starts along with production, distribution and utilization. On the left side, indeed, there is the Plastic Packaging Recovering Chain, i.e. the packaging producers, the product companies and the retailers, who produce the packaging, the products and sell them to the consumers. On the right side, instead, the Plastic Waste Recovering Chain is represented. The recycling process takes place in different phases: (i) the separate collection of waste (citizen); (ii) the collection of separated waste from a company (public or private) and the pre-sorting and cleaning of plastics; (iii) the sorting of different plastics and, (iv) the recycling, i.e. the sorted plastics are processed in order to have materials suitable for a new use.

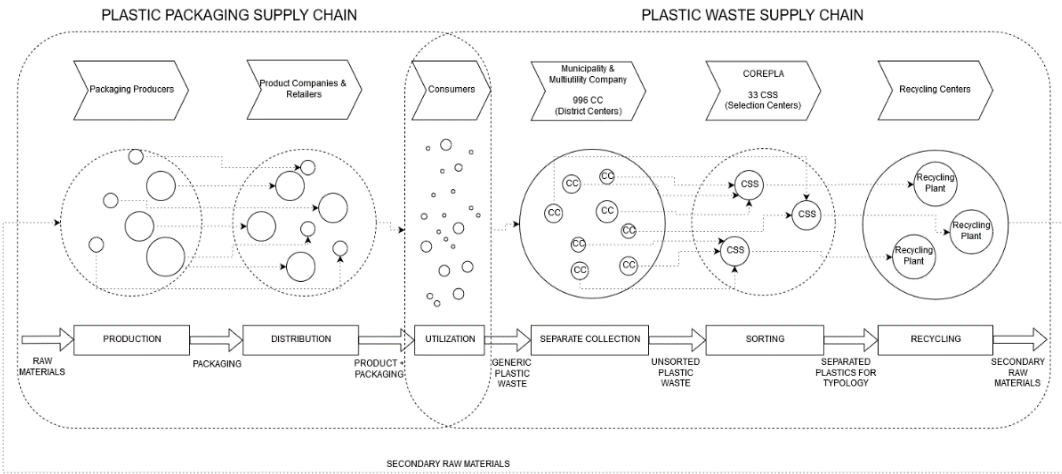

Fig. 1. Simplified plastic packaging value chain in Italy

3.4. The plastics ecosystem

Figure 2 represents the national Money and Material Flow (MMF) for the plastics recycling supply chain. The dashed lines represents the money flows, where the direction of the arrows means who pays who, while the filled lines represent the materials flows. The plastic packaging ecosystem, in terms of materials flows, starts from the producers, i.e. packaging and product producers, who use raw (primary or secondary) materials to produce the plastic packaging. Consequently, they sell the products, and the packaging, to the consumers.

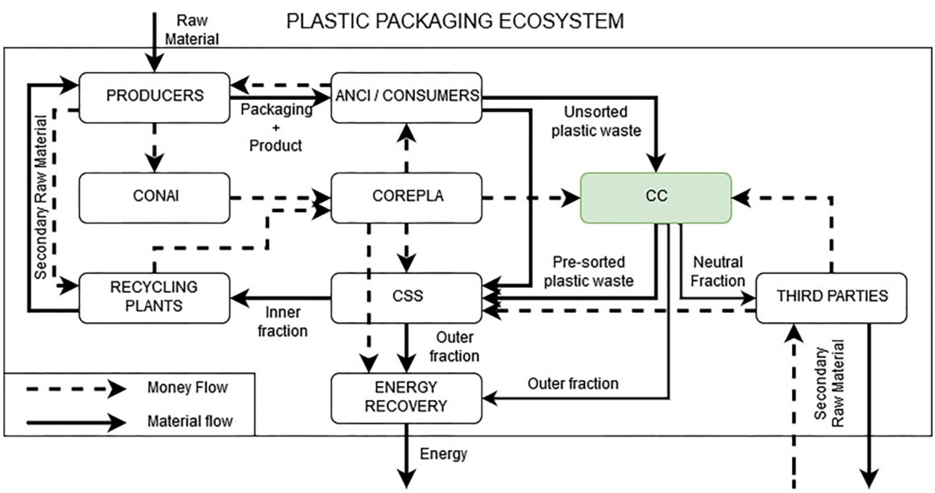

Fig. 2. Money and Material Flow for the plastic packaging supply chain in Italy

In the graph it is represented by ANCI ("Associazione Nazionale dei Comuni Italiani / National Association of Italian Municipalities") and consumers' box. Then the municipalities (i.e.

ANCI) collect the plastic waste with separate collection, generally through a private or public multi-utility service company, and bring the waste to the CC (the District Center), owned by a third party company or by the municipality/multiutility itself, for the pre-sorting and cleaning process, or directly to the CSSs (the Sorting Centers) owned by COREPLA's subcontractors. The CCs, and the CSSs, sort the plastic waste dividing them into 1) an inner fraction, i.e. the recyclable plastics; 2) an outer fraction, the waste part composed by other materials (glass, paper and not-packaging plastics) and 3) a neutral fraction, products not recognized by CONAI-COREPLA (Consorzio Nazionale Imballaggi, National Packaging Consortium). In Italy there are 996 CCs held by municipalities and local multiutilities while COREPLA holds 33 Sorting Centers (CSSs), scattered throughout the national territory (MISE, 2018): the choice of center happens according to a territorial proximity principle, in order to reduce both costs and transportation environmental impact. At this point, the material is ready to be recycled.

The outer fraction, generally, ends to District Heating (DH) plants, in order to recover the energy of the plastics by incineration, or to landfill. The neutral fraction is sold to third parties who recycle the materials and resell it on the materials' market. Finally, the inner fraction, the most valuable fraction of the plastic waste is brought to recycling plants which transform the waste into secondary raw materials, ready to be sold either again to packaging producers or for the production of other products. Although the Material Flow seems to be decentralized, involving several private and public stakeholders, from the municipalities to the citizens, include private companies, the Money Flow is completely centralized and guided by a unique actor, COREPLA, as member of the CONAI system of consortia which manages the whole post-consumer packaging material in Italy. COREPLA signs contracts directly with municipalities or operators, as District Centers or Sorting Centers, who receive the approval for the treatment by local public administrations. Indeed, the packaging ecosystem Money Flow can be read again starting from the packaging producers who pay a fee for each packaging sold on the market to CONAI, the general packaging Italian consortium. CONAI pays directly COREPLA for each plastic packaging. COREPLA, with the fees received by the private companies, pays 1) the municipalities, or the local multiutilities who collect plastic waste and 2) the owners of the District Centers who pre-sort and clean the unsorted plastic waste, 3) the subcontractors who own the Sorting Centers and the owners of the District Heating systems for Energy Recovery. Finally, the Recycling Plants, who receive the final sorted and split plastic materials, pay again COREPLA to receive the inner fraction of the plastic wastes and sell the secondary raw materials, after the recycling process, to the producers.

3.5. A case-study in Turin: a starting point to understand the complexity of plastics recycling chain

The selected plant is classified as a CC; it is a district center from which the selected plastics will be moved to the CSS, the Sorting Center. It deals with plastic packaging and other kinds of bulky waste, in fact in this case-study the authors choose to focus only on plastic waste. The plant holds ISO9001 (2015), ISO14001 (2015) and OSHAS 18001 (1999), certifications and it has the main goal of storing and selecting non-dangerous waste to facilitate the selection process to generate secondary raw materials to reintegrate in products' life-cycle.

The plant is authorized to treat up to 66.5 ktons per year of waste. In 2018 it treated 23 ktons of waste, fulfilling around 34.6% of its potential. This is an encouraging figure, as in the previous years the amount of generic plastic waste collected was lower. Piedmont increased from 2017 its amount of generic plastic collected by 14%. On the other hand, only around 19 ktons consisted of plastic packaging, while around 4 ktons made up the outer and the neutral fraction. According to the quantity of plastic packaging given to the CSS, COREPLA gives to the CC an economic reward. The price per ton varies according to the kind of packaging given to the CSS as described by Table 3.

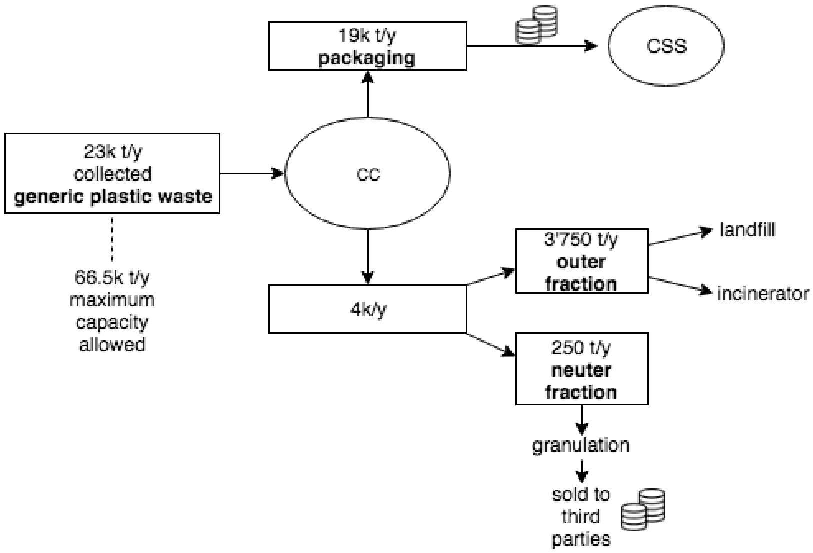

Fig. 3. Plant's Material Flow

Table 3. Flow of plastic materials and reward per tons on material (ANCI-COREPLA, 2014)

Flow	*Euro per ton*	*Description*
A	303	mono-material of urban origin
B	80	mono-material of non-domestic origin with a relevant quota of tracers
C	394	mono-material of urban origin, mainly CPL ("Contenitori Per Liquidi / Beverage Container")
D	295	multi-material of urban origin

Each flow has a maximum percentage of allowed outer fraction (FE - "Frazione Estranea"), in order to be accepted by the CSSs and COREPLA according to the national ANCI-CONAI agreement for the period 2014-2019: A) FE < 20%, B) FE < 20%, C) FE < 10% and D) $\%FE_{Plastic}$ < 22%. For the Flow D, $FE_{Plastic}$ is quantified according to Eqs. (1, 2):

$$\%FE_{Plastic} = \frac{PlasticPackaging * \%FE_{tot}}{PlasticPackaging + OtherPackaging} \quad (1)$$

where:

$$\%FE_{Tot} = \frac{FE * 100}{PlasticPackging + OtherPackaging + FE} \quad (2)$$

PlasticPackaging and *OtherPackaging* represent the amount of plastic and of other materials in tons. When only mono-material is given to the CSS the formula to calculate the economic reward is while, when the flow is multi-material, the economic reward is given by the formula where CN is the net fee, Cu the unitary fee per ton, IC the quantity of packaging in tons, FE the outer fraction in tons and Cfes and Cfer the unitary cost for selection and recovery of outer fraction, respectively. The COREPLA reward constitutes the main source of income for the plant.

On the other hand, the plant deals with different stakeholders, who influence the flows of incoming materials, as well as the end market of recycled plastics. The first actor which influences the plastic cycle is composed by the citizens who decide whether or not to respect the separate collection. Secondly, Amiat, the local multi-utility of the City of Turin, plays a key-role as the company which steers waste management, in which the plant plays an active role. Amiat collects waste, including plastics, which reaches the plant on a daily basis, taking it from selected areas of the city. Once treated by the plant, specific plastics are sent to specific CSSs. Specifically, the consortium buys plastic bales from the selected plant. Afterwards, in the CSS the bales of plastic material would be treated and separated in diverse types such as: colourless PET bottles (mineral water, soft drinks, etc.), blued PET bottles, PET bottles of other colours, high-density polyethylene bottles-HDPE; polyethylene film (bags, bottle packs, appliance packs, etc.) and mixed packaging (mainly rigid and flexible polyethylene or polypropylene). The complex network of stakeholders created by the plastic packaging ecosystem is depicted in Figs. 1 and 2.

3.6. Establishment of CONAI: an important actor for the recycling system of plastic packaging.

The regulation relating to the management and recycling of plastic packaging dates back to Legislative D.Lgs 22/97, the so-called "Ronchi Decree". This decree gave rise to CONAI, which manages exclusively the packaging waste. It clarified the current collaboration between public and private sectors: Ministries, Authorities and Public Administration, on one side, and Material Consortia like COREPLA (for plastics) on the other (CONAI, 2017). On the other hand, it led to the creation of a private market for the recycling of packaging (Pierobon, 2012). After that legal framework, several laws disposed by national and European institutions determined the conditions of work of COREPLA and CCs as the case-study.

As mentioned before, COREPLA only accepts plastics from packaging as it is under CONAI regulation (CONAI Environmental Declaration) which obliges packaging producers to pay a fee to guarantee the collection and the recovery of the packaging sold in the Italian market (extended producer responsibility). Thus, the recycling potentiality in Italy is not fully disclosed, as many plastic products are not accepted by CONAI (2018) and, consequently, they are discarded during the sorting and the selection processes within the CC and, afterwards, within the CSS plants. In the case of the selected plant, pre-sorting is useful to separate the plastic packaging from the non-packaging. These conditions and constraints depend on the legal and administrative barriers which regulate the whole process.

Currently, CCs as plants of plastic treatment receive compensation linked with the amount and the quality of separate collection. It decreases as the "outer fraction" increases with respect to the plastic packaging, i.e. the inner fraction, on the basis of the provisions of the ANCI-Conai Framework Agreement (Ciotti and Paravidino, 2018). As declared in the Agreement, the plant works on sorting only plastics from packaging into material to recycle and to use other potentially recyclable plastics for energy recovery. Although the amount of packaging flows is considerable, as COREPLA offers a financial compensation for 14 types of flows, the packaging constraint prevents a larger proportion of plastics from being sent for recycling. The Agreement defines as outer fractions, objects of daily use that are very common: plastic cutlery, toys, construction products and, more generally, any object that is not intended to be used as a packaging. For this reason, the 16% of the total amount of plastics received by the plant is considered by the Agreement as outer fraction, and it is actually sent to incinerator or to landfill.

At European level, the legislation seems to have taken a step forward, with the entry into force of Directive 2018/852, which provides for an extension of the responsibility of the packaging producer to ensure high quality and recyclability. This action could influence the future quality of input flows received by the plant; however it does not boost the recyclability of other plastic products.

To sum up, at legislative level there is a clear need to improve another aspect: the reusability and durability of plastic products. To reach these goals, four main administrative challenge are identified to improve the legislation about plastic reuse and recycling. They involve different policy fields: 1) taxes on the use of virgin plastics or differentiated value added taxes for recycled plastics; 2) reform of support for fossil fuel production and consumption; 3) introduction of recycled content standards, targeted public procurement requirements, or recycled content labelling; and 4) education and awareness campaigns in order to stimulate demand for products containing recycled plastics (OECD, 2018). The first step for plastic reusability is actually represented by Deposit Return System (DRS): 10 European countries have allowed more than 130 million citizens to return and reuse empty beverage containers (CM Consulting, 2016). However, this plan should be shared by all EU Member States, including Italy, to guarantee significant outputs. These aspects explain not only the quality of the work of the selected plant, but also its purpose in the current Italian plastics management ecosystem.

4. Conclusion

The plant considered in this case-study plays a relevant role in the plastic value chain. After an analysis of the flows (materials and money) from the plant and a careful regulations' evaluation, some interesting conclusions can be drawn. From an administrative and legal point of view, the renewal of the current legislation on management might be able to improve the whole recovery system; at the same time, it could open new scenarios for the plant. If this legal update took place, the plant would work with a wider amount of plastics which would be sold to recycling public and private companies. In particular, the D.lgs 22/97 should be updated, in order to include products different from plastic packaging, thus enlarging the range of recyclable products; the ANCI-CONAI agreement should be revised as well, in order to allow municipalities to bring to the CCs not only plastic packaging but other kinds of plastic as well. A relevant aspect which comes up from this research is that plastic recycling system is based on a material and product selection instead of only on a material one, indeed. Hence, from a recycling point of view, the material is the subject and not the product. Opening the access to the recycling process to all the products made of plastics could simplify the separation operations both from the citizen and the CCs, or more in general, the separation plant perspective. The regulation on products should be applied more to the recycle field, such as the Deposit-Return System for beverage containers, e.g. for glass bottles or plastic cups, while for the recycling field we should focus the attention on materials.

On the one hand, Chemistry and more in general the technological field, should continue its effort towards the innovation of materials that are easier to recycle. The challenging work in the research addressing an increasing sustainability for a pivotal material like plastic is jeopardized by the high performances required for this material. These requirements lead to a change in our behavior as consumers and this is an interesting challenge.

On the other hand, this "material" approach might be difficult for economic reasons because the payment for the recycling system should be made by the companies which produce plastic and not by the packaging producers. This could further hamper the cost-effectiveness of recycled plastic because, considering the cost of virgin plastic is influenced by the cost of oil, any additional cost bore by companies might be reflected in the final price of recycled plastic. A possible solution might consist in the introduction of tax relieves for the companies but the complex cost structure of plastic production should be further deepened to provide more insightful suggestions. Furthermore, the case study points out how plants as the CC considered continue to play an important role in the plastic waste treatment.

In conclusion, this research shows the future challenges which are going to be faced by every actor who want to change the process with a circular perspective. A circular approach might deeply change the function and the work of CCs in the plastic value chain and opens new scenarios of study.

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