Agricultural Plastic Waste Management

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Abstract: - This article aims at describing both the studies and results implemented in the framework of the H2020-EU research project “RECOVER: New bio-recycling routes for food packaging and agricultural plastic waste” which deals with the sustainability of innovative biodegradation processes for plastic waste and production, in any environmental, social, economic and safety matters. In such a framework, the POLOG University Centre (Livorno, Italy), reconstructed and analyzed the actual farm plastic waste supply chain, as described in the following sections. The first section is introductive and it has been intended as a primer to the most common different types of plastic materials. The second section has deserved to be a state of the art on the most relevant issues raised in plastic waste management. The third section deals with suitable approaches to address the environmental side effects of rapidly growing plastics production, use, and disposal. Some of these approaches were listed, such as physical treatment of the polymeric components, plastic reduction use and employment as much as mechanical and/or chemical recycling and energy recovery. The fourth section shows how some of the above main issues, which raise coping with plastic reduction and recycling, are suited to be coped with from a logistics perspective. Such logistics belong to the basic needs due to tackling any plastic waste supply chain, i.e. collection and transport to intermediate stock and final delivery to recycling plants and/or brownfields, applying the set of methodologies and techniques drawn from the well-known field of pick-up-and-delivery models. These last tasks become crucial when the main effort has addressed the enforcement of any feasible changes from the use of items made in old high environmental intrusive to their replacement with new agricultural and biodegradable plastics. The paper goes to end presenting shortly of a few suitable solutions that could be proposed and applied to the entire plastic waste supply chain. Finally, some concrete aspects of each phase of the supply chain were discussed and it was highlighted how much each of these can be best used in addressing the problem known throughout the world as the problem of the emergency of old plastic waste.

Keywords: - Plastic pollution and sustainability, Plastic waste recycling, management and collection logistics, Agriculture field, plastic waste biodegradability.

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1 Introduction

As well known, the global production of petroleum-based plastics keeps increasing in particular for low-cost, single-use applications, due to plastic strength, lightweight, and versatility, [1]. Petroleum-based plastic is diffused in a wide range of applications from the medical, and industrial fields, to domestic, packaging and agriculture, becoming an indispensable presence in our lives. In 2020 global plastic production was estimated at 367 million tons of plastics, of which 40.5% was used for packaging applications. In spite of most plastic used in packaging, being potentially recyclable, just about 34% of plastic waste was recycled, while over 23% was still released into landfills or natural environments, especially in the oceans, where 13 million tons of plastic have been estimated, [2]. Thus the undiscussed industrial and social benefits of plastics conflict with the concern for accumulation into the land and seas inducing very negative impacts on wildlife and human health, [3], [4], [5]. This article analyses the environmental sustainability of plastics in food packaging and agriculture, focusing on the main non-biodegradable plastic materials used on farms as plastic covers and mulching film.

It was estimated that about 40,000 km^2 of European farmlands are covered by plastic films. The agricultural plastics are mainly produced using synthetic petroleum-based non compostable polymers, while the supply of bio-based plastics remained low, due to the relative high cost of these last materials, [6]. The main plastics used in agriculture are low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), polyvinyl chloride (PVC), polystyrene (PS) and polyethylene (PET). The disadvantage of these materials is their production process, which generates significant amounts of CO_2 in the atmosphere causing global warming. Plastic recycling is currently the most widely used technique to minimize these impacts since it allows saving resources and consequently reducing carbon emissions and the amount of waste to be disposed of, [7] , [8]. In the life cycle of a plastic, including production, use and disposal we can identify several steps. Firstly, each supplier provides the raw material. Then the supplier processes the raw materials until they are ready for use. The supplier then provides to not only the plastics industry but also other industries that use plastic as raw materials for their products such as for example farms. Considering the process of plastic production from upstream to downstream, the whole system consists of several interrelated subsystems, listed below:

a) Primary raw material subsystem which is mainly resources from petroleum.
b) Production process subsystem which is making and processing plastics.
c) Plastic waste management subsystem which is collecting and transporting plastic waste and the final disposal process.
d) Plastic recycling subsystem which collects plastic waste that can be recycled by plastic waste collectors, sorting of plastic types, plastic milling, plastic washing, and drying of plastic debris which is then sent to plastic factories as secondary raw materials.

2 Plastic Waste Management: A Brief State of the Art

Plastic waste not treated properly refers to plastic often disposed of directly, without being processed. This can disrupt the environment such as the marine ecosystem. The reasons why people dispose of plastic waste directly are because the process to handle plastic waste is difficult and takes time. By the way, recycled plastic accounts for a percentage of 5% of the total production and receives the recycled plastic directly, from the production cycle, operating a real reverse logistic chain.

Fig. 1: Plastic Supply Chain.

Various methods have been used to deal with the issue of plastic waste such as the implementation of the so-called “4R” principle (Reduce, Reuse, Recycle, as well Refuse), but there are complications that come with each method. Many studies investigated the difficulties for plastic recycling. For example, Mariotti and co-workers, [9], analyzed the material and money flows, the study of plastic materials and the examination of the normative led to the identification of relevant key barriers.

In the agricultural field, plastics is delivered from the industry to farms through wholesalers and retailers as shown in Fig.1; after use, packaging, mulching films and other plastic products will become a waste. The waste is picked up by plastic waste collector devices and vehicles, then it is carried to plastic recycling plants or stored in some waste disposal sites. After that, the plastic can be processed and recycled. Fig.1 also shows the RECOVER project partners belonging to different agricultural plastic supply chain nodes.

In order to get a better understanding of the actual operations in farm plastic waste supply chain, the POLOG - Logistic Center of the University of Pisa (Livorno, It.) has implemented an on-line survey (https://survey.tages.it/recover/) in six different languages (English, Italian, French, German, Portuguese, and Spanish). The questionnaire has four different versions for different supply chain nodes like plastic manufacturers, waste treatment companies, distribution/warehousing companies and farms. Fig.2 shows the first two pages of the survey. At present, only 13 companies have completed the survey, divided in types as indicated in Fig.3.

Starting from the manufacturers, the three respondent companies are very different in dimensions: one has seven hundred employees while the other two sixty-three and ten employees.

Only the biggest one makes products containing recycled plastic for a percentage of 5% on the total production and receive the recycled plastic directly from the production cycle, operating a real reverse logistic chain.

An important feature regarding manufacturers is that all of them address as limiting parameters to recycle AWP (Agricultural Waste Plastic) are production cost, price inflation of bio-based raw materials and the presence of mixed fractions. It is clear that manufacturing companies must have incentives to use recycled plastics in their manufacturing processes. In this way, they can create both marketing and advertising advantages and can even allow a small surcharge if the final product can be sold as "green". Nevertheless, many manufacturers continue to rely solely on virgin plastic inputs, both because of their lower cost, but also due to inertia and uncertainty about the properties of recycled plastics, [10].

Fig. 2: First two pages of on-line survey.

Farms underline that AWPs are generally not mixed with other products and they are sent to mechanical/chemical recycling or incineration. The AWP production capacity goes from 100 to 1000 kg/year. They also said that there is no financial compensation for farmers who remove and manage their plastic waste. Of the three companies interviewed, only one recycles plastic waste with the following order of costs (high→low): LLDPE, LDPE, PS, PET.

Moreover, for farms, the use of biodegradation systems, creating spaces for plastic recycling by microorganisms, has a higher cost than transporting AWP to a landfill or petrochemical plant (also if they know it decreases environmental footprint). Usually, in each farm AWP are collected in dedicated containers and the farm does not use their trucks but third-party transport services, with a mean shipping of a container between 1/week to 1/quarter.

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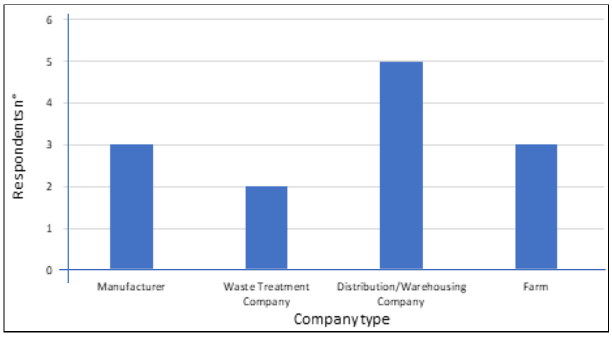

Fig. 3: Survey respondents by company type.

3 Possible Solutions

Several approaches have been proposed and are under consideration to address the environmental side effects of rapidly growing plastics production, use, and disposal, [12]. They include modifying the product design, lowering plastic amount such as through product light-weighting, and introducing alternative materials in the place of plastics, this could reduce the production, use, and disposal of plastics. The adverse environmental impacts derived from petro-plastic may be reduced even shifting to biobased or biodegradable plastics thus reducing their environmental footprint, [13].

- Improved management of the waste systems, by facilitating waste collection and increasing the recycling rates, would allow waste plastics being captured before they may be directed to the natural environment.
- Clean up and remediation activities, such as beach cleaning and technology to collect plastic from the oceans, would allow the removal of plastic already present in the natural environment, and get people more aware of plastic pollution
- Improvement of the plastic waste treatment, improving quality of recycled plastic, and consequently increasing recycling rate.

The most used solution is the waste treatment process, based on the physical properties of the polymeric material of the plastic. Indeed, polymeric materials can be classified as thermoplastics and thermosets. Thermoplastic is a type of plastic that can be processed, and thus even recycled by re-melting process. Plastics that are classified into thermoplastics include polyethylene (PE), polystyrene (PS), poly vinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), and polycarbonate (PC). While thermoset is a type of plastic that cannot be remolded because during overheating, thermosets tend to degrade without melting. Table 1 displays some of the most common usage thermosets items including epoxy resins, Bakelite, melamine resins, and urea-formaldehyde resins. Reduction of plastic waste can be achieved in four different ways:

1) Reduction in use.
2) Disposal and degradation by landfilling/incineration.
3) Reuse.
4) Recycle.

Reduction in use means limiting the use of plastic either by replacing plastic with other materials or changing material design in order to have a lighter product. Degradation is the process of damaging plastic structure that can be done by incineration with energy recovery, or by disposal in landfills where some plastic may incur in degradation, eventually by anaerobic digestion with production of biogas.

Reuse is the approach of reusing plastic that has used before. Recycling may be chemical, mechanical, etc.; in this process the plastic waste can be processed to be used again, or chemically treated to go back to monomers or other chemical blocks that can be used for producing the same plastic, but even different chemicals. In terms of plastic waste, the recycling process for solid plastics waste types is generally done in three ways: mechanical recycling, chemical recycling, and energy recovery.

Table 1. Manufacturer product types, characteristics and dimensions.

Company	*Product type*	*Weight*	*Dimensions*
LCI *Italy*	Pot 	0.1 kg	14 x 20 x 20 cm
TIPA *Corp.*	Compostable Films 	100 tons per year	180-250 cm
Bio-Mi d.o.o	Biodegradable mulch films 	25-30 kg	100-120 cm
Castellani *s.p.a.*	Packaging 	10 kg	100 x 120 x 170 cm

Mechanical recycling consists in separating, sorting, baling, washing, grinding, compounding, and pelletizing, [14]. This recycling process can be configured using closed and open loops where the application can provide a different final version of the recycled product. The closed-loop process will produce products that have properties similar to the original material, so they can be used as raw materials with high-additional value. A common problem associated with mechanical recycling is the degradation and mixing of polymers leading to loss of the characteristics that made the initial pre-recycled polymer desirable [11]. As the plastic qualities are degraded through the recycling process, some may not be able to be returned as input to new plastics, and are used to create less valuable, limited application, plastic products, [15]. Some of the current instances are:

- Park benches.
- Plastic lumber poles for gardens.

- Drainage pipes.
- Carpets.
- Railroad ties.
- Truck bed liners.
- Plastic roads.

The chemical recycling consists in the following steps:
Step 1) Chemical depolymerization: it is a chemical process by which the plastic waste is chemically reduced to its original monomers or other chemicals. It is suitable only for homogenous pre-sorted plastic waste streams such as PET, PU, PA, PLA, PC, PHA, and PEF. Chemical recycling can be done by chemolysis, pyrolysis, fluid catalytic cracking (FCC), hydrogen technologies, Katalytische Drucklose Verölung (KDV) process or Catalytic Pressureless Depolymerization process, and gasification combined with methanol production.
Step 2) Solvent-based regeneration: it is a purification process based on dissolving polymers in proprietary solvents, separating contaminants and reconstituting the target polymer. The process can be applied to several polymers.
Step 3) Thermal depolymerization and cracking (gasification and pyrolysis): These processes heat plastic waste in a low-oxygen environment to produce molecules from mixed streams of monomers that then form the basis of feedstock for new plastic without degradation. The main output is syngas or synthesis gas, [16]. Both gasification and pyrolysis have been considered for decades to create energy (syngas burned to drive steam turbines) from municipal waste that didn't get a commercial success due to a combination of poor economics, high energy consumption requiring supplemental fuel, fires, explosions, emissions, and residues. These processes are also used to create 'plastic to fuels' (fossil fuels), as oils and diesel can be generated in addition to syngas. Most recently biotechnology has been considered for plastic degradation and waste management, thus the depolymerization using enzymes, or bacteria is a technique still at an experimental and research stage. One if the studied techniques for example uses a bacterial hydrolase enzyme to reduce PET to its monomer, [17]. The bacterial enzyme is based on a naturally occurring bacteria that has subsequently been modified by scientists to degrade PET more efficiently, claiming a 90% depolymerization within 10 hours. More and more examples of use of enzymes, bacteria but even worms, insects and larvae for degradation of plastic can be found in the literature evidencing the trend for looking to natural, green chemistry, biotechnological approaches for the plastic waste treatment.

The last approach, we address is valorizing the plastic waste for energy recovery, this is conducted by burning plastic waste for electricity production, this process reports an efficiency above 90%, [18]. The process is proposed for plastic waste that cannot be recycled, but considering the need for energy is widely applied even to recyclable plastic. Main concern for incineration is the management of ashes and air emissions making it difficult to get population acceptance of an incineration plant nearby. Most recent treatments consider the transformation of plastic to fuels that might 'substitute' fossil fuels and offset oil, gas, and coal. By the way the process still needs investigation and upgrades, not to result in just compressed post consuming plastic. One promising approach of this process is the conversion of plastic waste to hydrogen, which is a clean burning fuel. However, to date, hydrogen production may require energy-intensive processes that could even compromise the benefits of reducing the carbon footprint.

3.1 Logistic and Distribution Solutions

Solutions must be studied starting from the entire plastic waste production chain and researching how each node in the supply chain can give its own help to solve the problem. For example, industries are expected to work together by creating and implementing a plastic waste management system using a reverse logistics system where plastic waste is returned to the factories that produce it. Afterwards, factories will manage the plastic waste by recycling and reusing them. Reverse logistics is the process of planning, implementing, and controlling the flow of raw materials, work in process, finished goods, and related information, which flows from the point of consumption to the point of origin efficiently, [19]. Logistics generally bring products to customers.

Reverse logistics is the opposite of the previous process, where the product or goods are brought from the customer to the distributor, or to the manufacturer, which includes reprocessing or disposal. The transfer of the product or item is carried out through a supply chain network, like the one shown in previous Fig. 2. Another way to manage plastic waste is to optimize the plastics packaging supply chain. The plastics packaging value chain starts along with the production and continues with the distribution and utilization. On the left side, indeed, there is the Plastics 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. Appropriate handling, treatment, and disposal of waste by type reduces costs and contributes significantly to protecting public health [20]. Segregation is another important element of the waste management supply chain, and it should always be the responsibility of the waste producer, should take place as close as possible to where the waste is generated, and should be maintained in storage areas. The same system of segregation should be in force throughout the country. From the segregation it starts the waste logistic and transport phase. Segregation is followed by the Collection/ Storage phase that can be linked also to new ways to optimize distribution. For example, waste containers can be implemented with volumetric or weight sensors so as to be able to have a clear communication to distribution companies about available capacity so as to optimize waste recovery according to vehicle capacity. Moreover, the storage can be followed by a Special Packaging phase, depending on the measure and volume of the waste. It can be useful to package waste following the standard dimensions used in transportation like pallet dimensions or other systems, so also to optimize the following Transportation/Distribution phase. For this last part it can be useful to have a Routing optimization system to decrease the transportation distance and time (especially for perishable products). This system can be linked to the municipal road management system in order to avoid road congestion and other critical features.

3.2 GIS Models and Optimal Management of Large Bioplastic Waste Collection

Distribution logistics is a cost element that should not be underrated in any process chain. For this reason, its optimization becomes an indispensable element to reduce the costs of the supply chain itself. In this regard, a series of heuristic algorithms have been able to solve the so-called Traveling Salesman Problem-TSP, or better Vehicle Routing Problem due to capacity and time constraints, elaborated and solved by a set of programming procedures belonging to Branch & Bound, Greedy or Patching methods. These algorithms can be applied both in the ex-post phase, i.e., on-time distribution of constraints and customers, as much as in real time by receiving reservations for deliveries/collections that vary over time. Compared to the latter example, the case of plastic recycling introduces an extension based on the use of radio frequency communication-active RFID. In practice, it is a question of equipping each container or bin, deriving from the sorting of recycled plastic with an activated/sensor, possibly connected to a volumetric filling and/or weight sensor. The RFID sensor communicates exposure data of web cloud volume and/or weight value via web to allow the operator in charge of its withdrawal to know the places of real exposure of the plastic materials and their volumetric characteristics and/or weight. Such a result has been offered by some commercial packages. For instance, one among others is ArcGIS™, which belongs to the popular real-time software engine of ESRI's ArcGIS™ software, [21]. ArcGIS™ operates in real time by setting up the corresponding Vehicle Routing problem, together with all path and capacity constraints, as much as time windows constraints, if any, or any other kind of constraints that must be included into the model representation of real world operational conditions in order to allow for effective optimization. The result is an optimized vehicle delivery tour, in respect to its costs and delivery times, which is to be followed by the vehicle driver, or sent directly to an autonomous vehicle driving control device, [22].

Fig. 4: Volvo autonomous refuse truck automated vehicle (courtesy by [20]).

As a practical example in such a direction, a few years ago, Volvo Automotive Group presented an autonomous refuse truck (Fig. 4) which is an automated vehicle and it is equipped with sensors that continuously monitor the vehicle's path. This last is pre-set up and the truck drives itself from one wheelie-bin to the next. Then the driver walks ahead of the reversing vehicle, and he is only focused on refuse collection. This way, the driver does not have to climb into and out of the cab every time the truck moves to a new bin.

Fig. 5: The waste collection process through GIS coupled with RFID sensor technologies, [21].

From the point of view of methodology, the application of a GIS has addressed the core of the control and management system of the vehicle fleet. The main tasks are rooted in the optimal definition of the transport of plastic and solid waste from the individual collection points (pick-up nodes) to the plant, or more, for delivery and storage, allowing you to identify, vehicle by vehicle, the path of minimum cost/distance. The GIS model considers the capacity of the vehicles used, gets information on the road network available, dynamically updates the storage availability of the treatment plant, and at the same time interrogates the sensors at the collection points to plan collection trips based on actual needs. For this last aspect, in the specific case of plastic collection from large users, it is possible to place in each of them a removable instrumented container with volumetric measurement of the filling level. When the sensor requests collection, the equipped vehicle picks it up leaving an empty one in its place: one trip and two services. Fig.5 depicts the waste collection process. In the past decade, the applications of GIS systems in the waste collection sector have reached, almost all over the world, compared to the cost of the previous traditional methods of managing the collection and storage service. Roughly speaking, the expected savings range from 25% up to 50%. More in detail, the technical literature report estimations are about 20% less than the annual mileage, and 30% and above for the collection times. These savings also translate into environmental benefits, such as corresponding in mileage shortages and then reduced tons of CO_2 emissions per year.

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