Current Opinion in Chemical Engineering

ID COCHE-D-20-00043 " Plastic end-of-life alternatives, with a focus on the agricultural sector"

--Manuscript Draft--

Manuscript Number:	COCHE-D-20-00043R1
Full Title:	ID COCHE-D-20-00043 " Plastic end-of-life alternatives, with a focus on the agricultural sector"
Article Type:	Frontiers in Chemical Engineering (2021)
Short Title:	Plastic EoL alternatives
Keywords:	agricultural plastic waste; 3E; 3R; Extended Producers Responsibility; Sustainable Development Goals
Corresponding Author:	Riccardo Scalenghe, PhD Università degli Studi di Palermo Palermo, ITALY
Corresponding Author's Institution:	Università degli Studi di Palermo
Corresponding Author E-Mail:	riccardo.scalenghe@unipa.it
First Author:	Antonino Galati, PhD
Order of Authors:	Antonino Galati, PhD
	Riccardo Scalenghe, PhD
Abstract:	The end of life (EoL) of plastic polymers depends on when they stop being considered a resource and begin to be considered a waste. Even with dynamic management, plastic pollution will increase in the coming decades. Reduction strategies focus on reducing the quantities of materials used in the construction of individual objects for packaging, support for reuse and recycling, incentives for gathering low-value plastics, awareness, and simplification. The agricultural sector, a sector in which the use of plastic is (apparently) not high, needs to combine environmental, social, and above all economic aspects, which can help entrepreneurs in the sector to optimize the recycling process.
Author Comments:	

Plastic end-of-life alternatives, with a focus on the agricultural sector

Antonino Galati, Riccardo Scalenghe

Abstract. The end of life (EoL) of plastic polymers depends on when they stop being considered a resource and begin to be considered a waste. Even with dynamic management, plastic pollution will increase in the coming decades. Reduction strategies focus on reducing the quantities of materials used in the construction of individual objects for packaging, support for reuse and recycling, incentives for gathering low-value plastics, awareness, and simplification. The agricultural sector, a sector in which the use of plastic is (apparently) not high, needs to combine environmental, social, and above all economic aspects, which can help entrepreneurs in the sector to optimize the recycling process.

Abbreviations APW (agricultural plastic waste); 3E (energy, economy, environmental); EPR (Extended Producers Responsibility); EPS (expanded polystyrene); EVA (ethylene-vinyl acetate copolymer); HDPE (high-density polyethylene); LDPE (low-density polyethylene); PC (polycarbonate); PET (polyethylene terephthalate); PLA (polylactic acid); PMMA (poly-methyl-methacrylate); PP (polypropylene); PS (polystyrene); PVC (poly-vinyl chloride); PU (polyurethane); 3R (reuse, reduce, recycle); REACH (registration, evaluation, authorization and restriction of chemicals); SDGs (Sustainable Development Goals); TOC (theory of constraints)

Introduction

End of life (EoL) consequences depend on when and how a plastic object stops being considered as a resource and begins to be considered as waste. When an object finishes playing the role for which it was designed, the best EoL option is its reuse. The recycling option is less worthy but still effective. Composting (in the case of so-called bio-based polymers only) and transformation into energy follow [1]. If the widespread, although proscribed, practice of disposal straight into the total environment did not exist, burial into landfill would be considered the least suitable option [2], while upcycling processes, which transform the waste into valued goods, are considered the best [3]. An example is converting polyethylene (PE) into long-chain alkyl-aromatics, which are then sulfonated to make biodegradable surfactants [4].

Our review contributes to enriching research in the field of plastics management by aggregating current knowledge on plastic disposal and management (Figure 1) from the economic and environmental points of view, with a focus on the agricultural sector. This sector is not a key contributor to the production of plastic waste, but in some production segments it is necessary to find alternative solutions to respond to a growing demand for sustainability.

Sorting of polymers

Plastic polymers have extremely different product characteristics and market values; for instance polyvinyl chloride (PVC) has a market value per tonne which is half that of polyurethane (PU) (source: Plastic Information Europe). These reasons make separation crucial for recycling, although it is sometimes uneconomical to separate the different polymers. So, immiscible polymer blends and polymer blending are a fast growing sector of polymer engineering to produce innovative constituents. However, immiscibility may lead to poor properties, both physical and mechanical, including interfacial bonding. Therefore, research efforts have focused on compatibilizer to modify the interfacial bonding and mechanical properties. To improve compatibility, compatibilizers are intended to improve the interfacial activity by reinforcing the interface [*e.g.*, 5].

Lessons learnt from a more ancient, non-crystalline transparent amorphous solid: glass

Glass is one of the oldest synthetic materials, dating back to the third millennium BC, while plastic is one of the newest, appearing only in the last century. In Europe, the REACH[1] (registration, evaluation, authorization, and restriction of chemicals) regulation (EC 1907/2006) considers glass a substance of unknown or variable composition, complex reaction products, or biological materials, while most plastic polymers are considered as substances of very high concern. Glass and plastic(s) have some properties in common as both are made by cooling a liquid, presenting a reversible transition phenomenon that allows them to be recycled. However, although glass can be recycled virtually infinitely', this opportunity is strongly influenced by the collection of the material after it has been used. Plastic is often down-cycled when the final quality of the recyclable material is compromised, and this happens frequently due to the multitude of polymers used and their immiscibility. The final fate of plastics may be energy production, which is not the case with glass. In both cases, 3R (reuse, reduce, recycle)[2] is the best management strategy for EoL products [6 (•)]. In the case of glass, reuse would be applicable to some beverage containers at the level of local distribution networks; the technical problems here are the sanitization of the material used as well as the resistance of the object over time. The reduce strategy, which means limiting the quantity of material in final objects, shows the same technicalities as are applied to similar plastic objects made of different polymers. Recycling means open-loop processes (*i.e.*, product recycling when an EoL material is considered an additive matter to be transformed before reuse) or closed-loop recycling (*i.e.*, material recycling when an EoL

[1] REACH makes the industry accountable for evaluating and managing the risks posed by chemicals and for providing suitable safety information to their users. It is the European Union's controlling structure on chemicals and their non-dangerous use.

[2] 3R is the best strategy for the management of EoL products: reducing the quantity of EoL products, reusing parts of products or whole products that would otherwise become waste, and recycling, while only EoL products that do not fit into the 3R scheme become ultimate waste.

material becomes a secondary raw material). In the case of plastics, an open-loop process may end in road building [7 (•)] or building materials [8], but compatibilization[3] is the key to the success of plastics recycling [9].

In the case of glass, the main complication depends on the presence of ceramics in EoL products (*e.g.*, small pieces cause imperfections in final products, while bigger pieces, > 5 mm, lead to severe instabilities in the gob formation process) and the proportion of different colours in the cullet. So, sorting is mandatory to separate according to colour: brown glass can only be recycled into brown containers, and green glass can only be used to make green bottles [6 (•)]. Plastic materials are distinguished into many more classes so that they can be recycled, but it is essential to reprocess them separately [10]. With regard to colours, in the case of plastics there is the important theme of black plastics [11 (••)], which are substantially non-recyclable and potentially toxic.

Extended Producer Responsibility

Thirty years ago, Thomas Lindhqvist introduced the concept of extended producer responsibility (EPR), a policy approach under which producers are given a financial and/or physical responsibility for the treatment or disposal of post-consumer products through reuse or buy-back within a recycling programme; the producer may choose to delegate this responsibility to a third party who is remunerated for used-product control, a producer responsibility organization EU member states and Canadian provinces have familiarized EPR [12], ranging from mandatory principles to voluntary agreements between administration and production to deliberate industry initiatives. A good example is the National Consortium for the Management, Collection and Treatment of Used Mineral Oils (CONOU) conceived to carry out separate collection of used lubricating oil. In the case of

[3] Compatibilization is when a substance is added to an immiscible polymer blend to increase the stability of the system.

plastics, a target objective is that all packaging placed on the EU market is either reusable or could be recycled in a cost-effective way by 2030 [13], where EPR schemes may sustain finance action to curb littering [14]. Challenges connected to the production can be turned into opportunities [13, 15] by simultaneously increasing the source-segregated collection rate and the recyclability of all products. However, recyclers are the most fragile part of the system as they have to deal with market variation and fixed operational costs, so, even with a high collection rate, recycling of certain polymers would not be economically profitable [16].

Plastics in the agricultural sector

The plastic conversion demand for the agricultural sector in 2018 was 3.4% (*source*: PlasticsEurope), but plastic materials are crucial constituents of the reduced-input systems, facilitating the reduction of the use of several resources, helping to increase crop production and food quality, allowing for vegetables and fruits to be grown whatever the season.

An important initial clarification, APE Europe, the professional representative body of plastics for agriculture in Europe, states that agri-plastics can only be considered as non-packaging plastics invoking specific Extended Producer Responsibility framework in EoL management [17]. That said, a wide range of plastics tools are used (Figure 2), including bags (fertilizers, seeds, feed), containers (agrochemicals), pipes (drainage and irrigation), films, nets, mesh, strings, ropes, and trays. This multitude of production tools leads to the coexistence of many polymers, including polyolefins [PE, polypropylene (PP), ethylene-vinyl-acetate copolymer (EVA)] and PVC, polycarbonate (PC) and poly-methyl-methacrylate (PMMA). Polymers are accumulated in different quantities and have extremely different levels of 'reusability' or 'recyclability'. To give an example from a niche crop, for every kilogram of strawberries, 86 g of plastic polymers are used [18]: 4.2 tonnes of polyethylene terephthalate (PET) per farm per year, 0.6 of PP, 50 kg of polystyrene (PS), 50 of high-density polyethylene (HDPE), 10 of low-density polyethylene (LDPE), and 20 of LDPE+EVA. Given their low bulk density, they occupy impressive volumes, for instance expanded polystyrene (EPS), which is essential for plant containers, is accumulated to an extent of two cubic metres for each kilogram of strawberries grown [18].

Plastic films are among the most important materials: in mulching, they directly affect the yield, earliness of cropping, product quality, weed and microclimatic control, and solarization. Their use is so massive that methods for mapping agricultural plastic waste (APW) have been developed using remote sensing [19]. EoL film collection is problematic and substantial parts stay in the fields, generating fragmentation [20, 21] (an effective graphical abstract [20] summarizes options and total impacts), which leads to the popular, and feared, microplastics, of which we talk a lot but know, actually, not much, starting with their classification (some authors suggest an upper limit of 5 mm [22] (•)). When a mulched crop is harvested and the field is ploughed, small fragments could be mixed in with the soil. Solutions to deal with plastic debris may envisage alternative approaches, from biodegradable to thicker and more resistant (and more expensive) mulches. A mulch is considered biodegradable when it has a biodegradation threshold of 90% within two years (standard EN-17033), but an individual crop lasts less than six months in the field. Longer-lasting films affect both the final cost of the product and their management (subsequent removal and reinstallation), especially in terms of the quality of the work and effects on the well-being of workers (e.g., EoL films accumulate molecules spread over the crop cycle) (Figure 3). A single solution probably does not exist, as there is always at least one constraint. Perhaps, for each specific situation, it would be appropriate to apply a management philosophy, the theory of constraints (TOC)[4] [23].

[4] TOC interprets systems as being limited in reaching their objectives by a very small number of constraints and uses a focusing progression to recognize the constraint, reorganizing the rest of the system around it.

APWs are resources more than problems; examples span from the production of microgreens,[5] where recycled polyester, polyurethane (PU), or PET becomes a substrate [24] to recycled materials with anti-erosion functions, for example, sands reinforced with PET or PP fibres, to the consolidation of transit areas, including asphalt [7, 25]. In all cases, the technological 'keystone' is compatibilization [5].

Alternatively, new materials have been developed in recent years to address the unsustainability of both traditional plastic materials and some recycling processes adopted. Among these, biodegradable or oxo-degradable plastics, that at the end of their life can be buried in the soil or alternatively composted on farm, allowing to overcome environmental and disposal problems [26]. Comparing these two alternatives, Sintin and colleagues [27] find that the degradation process is faster in the form of compost than through burial. The use of biodegradable plastics does not only produce an environmental but also an economic benefit. Velandia and colleagues [28] comparing the use of PE and BP film in Tennessee Pumpkin production, find that the use of bio-degradable films, in the face of a higher price, entails a sensitive improvement in the profit due to a reduction of the labour cost associated with the PE mulch removal and disposal. The price of biodegradable films and the cost of labour are two important discriminants in the transition process from the use of PE and those of biodegradable plastics. A recent study on the farmers willingness to pay for biodegradable films in relation to the market price shows that farmers' willingness to pay decreases as the market price increases [29].

The accumulation of plastic from agricultural activities raises concerns for soil health, macro- and micro- plastic residues have negative effects on both above-ground and below-ground parts of crops affecting both vegetative and reproductive growth [30-32]. In particular, Gao et al. [31] observed significant yield decrease starting from 240 kg ha^{-1} of plastic residues.

[5] Microgreens are visual and flavour ingredients used to enhance the appeal of fine-dining dishes

A Focus Group of the European Commission on “How to reduce the plastic footprint in agriculture?” [33], recognising the main and most urgent needs, proposes the identification of the main use and properties of plastics in farming activities, including the identification of the indirect sources [35]. Plastic waste management is an additional cost that has to be covered: the EoL plastics collection and storage is a supplementary effort for farmers. However, an inappropriate collection and bad storage lead to contamination of the total environment [33]. Plastic polymers must be robust enough to be simply collected without producing debris: an effective removal and collection of EoL plastics is critical to enable appropriate management [34].

Economics of EoL alternatives

In sectors where there is intensive use of plastic material, there is a need to identify sustainable solutions to reduce the impacts of plastics based on a circular economy [25]. Two issues still remain open and at the same time little explored, linked, on the one hand, to the economic and environmental feasibility of the proposed solutions and, on the other, to the acceptability of these alternatives among farmers in relation to their willingness to adopt behaviours that are more responsible.

In many regions, the APW disposal options are on-site burning, on-site burial, disposal in landfills, and illegal dumping [36], which have negative effects due to the release of hazardous substances [37–40]. The adoption of these practices is driven (mainly) by the difficulty of managing the recycling process, due to the complexity of the materials or the low quality of the same products and due to the high costs of transport, storage, and transformation, which do not justify the farmers’ commitment and investments [41, 42] (Figure 1 and 4). This has led to the development of more sustainable alternatives such as recycling, which, among the solutions, is the one most in keeping with the circular economy paradigm in which plastic is reused or transformed into products, some with high value-added [36]. Recycling is not always a viable option, but its affordability depends on the type of plastic, the degree of contamination, and adequate sorting [37] and additionally it has high management costs [43]. The Energy, Economy, Environmental (3E) index [40], which was built based on energy, economic, and environmental parameters associated with different plastic waste disposal practices, shows that landfilling is the most inefficient system. The conversion of plastics into tar for construction of roads and into concrete for the construction of buildings, however, is a highly advantageous solution, since, compared to the alternatives studied, it generates low emissions and offers high economic and environmental sustainability benefits. Instead, recycling is an advantageous system from the energy and environmental points of view but not economically [40]. However, the opportunity to generate valuable products depends on the recycling processes adopted, whose choice is strictly related to the characteristics of the recycled material and the costs associated with the processes [34, 44]. Mechanical recycling is one of the most common solutions for the disposal of APW, but as Horodytska and colleagues [45] underline, even if, on the one hand, this process is favoured by the fact that often in agriculture there are high quantities of homogeneous materials (single polymer waste), on the other hand, the operations of washing, shedding, drying, and pelletizing and the low quality of the material to be recycled result in excessive costs that make this process uneconomical. These obstacles are amplified in the case of plastic mulch, which is often contaminated with agrochemicals that make it unsuitable for either landfilling, due to the risk of leaching of harmful substances, or recycling, since its treatment requires a laborious process and high related costs [41, 45]. In these cases, recycling is an effective alternative only if the contaminants do not represent more than 5% of the total weight of the mulch [46]. A different solution for plastic recycling is the adoption of chemical processes based on the decomposition of polymers into monomers intended for the production of new products and other high-value compounds

[44]. The use of pyrolysis for the transformation of APW into PE is financially sustainable, even if the plant is not used at full capacity [35]. However, in sectors characterized by small enterprises, it is crucial to create economies of scale [35, 40, 44]. In terms of reuse, combining four different irrigation levels with diverse recycled plastic materials used for mulching, coming from hostels and farmers' residences, the most advantageous solution in terms of the benefit-cost ratio is associated with the use of black plastic mulch, even if in terms of initial investments the use of wheat flour bag mulch is the best alternative mainly for small and marginal farms [47].

Farmers' attitudes towards recycling programmes

Regardless of the alternatives currently available for the recycling of APW, empirical evidence suggest that farmers' participation in recycling programmes depends, on the one hand, on the complexity of waste management (and also in relation to the legislation, which may not make the APW disposal a simple process), and, on the other hand, on their willingness to adopt virtuous behaviours. Canadian farmers are concerned with the proper disposal of agricultural plastics and are willing to behave responsibly and to pay to fund recycling programmes [42]. The choice of US producers of organic strawberries [48], although bioplastics are not ideal for organic crops, confirms that the use of bioplastics as an alternative to conventional plastic material depends on the awareness among farmers about both the negative consequences for the environment and the ethical value of their choice. The farmers' choice to recycle plastic material depends, as previously emphasized, on the type and volume of plastic generated. On the one hand, the type of plastic influences the choice of the alternative to be adopted, taking into account that there are low-value plastics that are complex to manage and mechanically recycle and are therefore preferably disposed of in landfills [42]. Similarly, the volume of plastic produced can make one alternative preferable to the other in relation to the cost of the alternative, which must always guarantee profitability to the company to allow it to remain competitive on the market [49]. Evaluating the propensity of strawberry producers to recycle EoL plastics [18], it turns out that this virtuous behaviour is more frequent among young farmers with a higher level of training. If, on the one hand, the costs of managing the disposal process represent one of the main discriminating factors in the choices of farmers, on the other, national policies specifically linked to recycling assume a significant importance, given the influence they can have on the APW management processes [50]. In line with this, it was found that the size of the company is a determining factor [51]. In fact, while small and medium-sized farms opt for the payback mechanism, large companies prefer tax credits, although the latter, as emphasized by the authors, could have distorting effects on the market and on the environment. A discriminating factor is the type of crop, highlighting that while tax credits are preferred for crops that require a low use of plastic material, due to the low transaction costs, the subsidy tool is preferred in sectors that make extensive use of plastic and where more complex management is required [52].

To date, In Europe, a regulation on the management of agricultural plastic waste does not exist. A general strategy emerged 2015 with the adoption of the "Action Plan for the Circular Economy" [53], and subsequently with the “European Strategy for Plastics in a Circular Economy” [54]. With this latest communication, the Commission outlined the EU strategy to guide the transition to a more circular plastics economy in the near future by providing specific measures. With reference to agricultural plastics, the Commission suggests to national authorities and industries to introduce EPR in order to provide incentives for plastic recycling (Annex II) [55], is the most effective measure that can contribute more to the achievement of EU objectives also in the agricultural sector. The Commission also proposes as key measures a better use of taxation or other economic instruments to improve the quality of recycling. Some recent studies analyzed the acceptability by farmers of some policy measures that could encourage a more farmers’ responsible behavior, including subsidies, tax credit, and pay-back under EPR scheme [52, 56]. The authors find that tax credit is the most favored tool among farmers, particularly in large farms, probably due to the complexity and costs associated with the waste management system, while for small and medium-sized farms pay- back EPR scheme. This finding underlines the importance of defining adequate and targeted policy tools in relation to the characteristics of the companies and for an effective implementation of the European strategy.

Concluding remarks

Even in the best positive scenario and with vigorous management, plastic pollution will increase in the coming decades [58 (••), 59 (•)]. The reduction strategies are pre-consumption measures, such as reducing demand (upstream), and post-consumption measures, such as collection and recycling (downstream). Upstream measures, which provide for the direct involvement of industries in synergy with public stakeholders, focus in particular on the issues of reducing the quantities of materials or promoting the use of alternative materials. A dramatic example is that of bitumen additives; that is, the addition of specific polymers increases the rheological properties and stability in asphalt binder [60]. These additives are transported in flexible intermediate bulk containers, also known as big bags. These industrial containers are made of plastic which is not reused (since it is uneconomical) but not even recycled, as the polymers they are made of are not compatible with incorporation into asphalt. Their EoL is landfill after only one use. Assessing the feasibility of substitution with alternative materials, finding an economically practical solution to efficiently manage flexible plastics will be crucial for disentangling the plastic pollution issue [58].

Rigid plastics dominate recycling due to the relative ease of collection and sorting. Downstream measures provide for the concrete support for reuse or recycling, provided directly to the user by incentivizing the gathering of low-value plastics (multilayer plastic, flexible monomaterial, and multimaterial [58]). In line with this, the EU strategy propose to considers the opportunity related to the introduction of the Extended Producers Responsibility or other policy tools in order to provide incentives to encourage the recycling of plastics in various areas including the agricultural sector. And, maintaining a constant plastic demand over time is critical in order to ease the total need on virgin plastic [61 (•)]. Furthermore, the final consumer must be helped in terms of awareness coupled with simplification [17].

The exemplified agricultural sector shows that there are many factors influencing farmers' choice to participate in recycling programmes, which depend in particular on costs and the availability of alternatives. Knowing the economic feasibility of alternatives is a *conditio sine qua non* to sustain more virtuous behaviours. The reorganization of the plastic value chain, from a circular economy perspective, becomes a priority that requires investments and concerted actions among all the stakeholders in the chain for the creation of vital markets for recycled plastics.

Conflict of interest statement

Nothing declared.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors would like to thank Cristina Cavallo Design for infographics, and CNEX Studio Corporation/視納華仁文化傳播股份有限公司 for allowing the use of the image from the movie Plastic China.

References and recommended reading

1. Wienchol, P., Szlęk, A., Ditaranto, M. (2020) Waste-to-energy technology integrated with carbon capture – Challenges and opportunities. Energy 198, 117352, DOI: 10.1016/j.energy.2020.117352
2. (•) Chen, Y., Cui, Z., Cui, X., Liu, W., Wang, X., Li, X.X., Li, S. (2019) Life cycle assessment of end-of-life treatments of waste plastics in China. Resources, Conservation and Recycling 146, 348–357, DOI: 10.1016/j.resconrec.2019.03.011.

   This paper assesses EoL scenarios for plastic wastes (mechanical recycling, incineration for energy recovery and landfilling) which is part of the current concern about the suitable handling and management of plastic during its EoL. This article studies the effect of each EoL scenario from a point of view of environmental chemical risk.
3. Weckhuysen B.M. (2020) Creating value from plastic waste. Science 370, 400–401, DOI: 10.1126/science.abe3873
4. (•) Zhang, F., Zeng, M., Yappert, R.D., Sun, J., Lee, Y.H. Lapointe, A.M., Peters, B., Abu-Omar, M.M., Scott, S.L., (2020) Polyethylene upcycling to long-chain alkylaromatics by tandem hydrogenolysis/aromatization. Science 370, 437–441, DOI: 10.1126/science.abc5441

   A virtuous example in upcycling the recycling of one EoL plastic polymer.
5. Ahmadlouydarab, M., Chamkouri, M., Chamkouri, H. (2020). Compatibilization of immiscible polymer blends (R-PET/PP) by adding PP-g-MA as compatibilizer: analysis of phase morphology and mechanical properties. Polymer Bulletin 77, 5753–5766, DOI: 10.1007/s00289-019-03054-w
6. (•) Lebullenger, R., Mear, F.O. (2019) Glass recycling. In: J.D. Musgraves, J. Hu, L. Calvez (Eds.), Springer Handbook of Glass. Springer Handbooks, DOI: 10.1007/978-3-319-93728-1_39

A primer in glass recycling extremely useful for comparison.

7. (•) Santos, J., Pham, A., Stasinopoulos, P., Giustozzi, F. (2021) Recycling waste plastics in roads: A life-cycle assessment study using primary data. Science of the Total Environment 751, 141842, DOI: 10.1016/j.scitotenv.2020.141842

This paper, based on the outcomes of a LCA analysis, drives the attention on EoL PE plastics re-employed in bitumen. They conclude that recycling rigid PE polymers to produce synthetic asphalt aggregate (as aggregate replacements) is minimally beneficial. Viceversa, soft plastics as a polymer for bitumen modification delivers significant environmental benefits. Moreover, recycling locally amplifies these benefits.

8. Cruz-Estrada, R.H., Guillén-Mallette, J., Cupul-Manzano, C.V., Balam-Hernández, J.I. (2020) Potential use of waste from tree pruning and recovered plastic to obtain a building material: Case study of Merida, Mexico. Waste Management and Research 38, 1222–1230, DOI: 10.1177/0734242X20928404

9. Wu, S., Montalvo, L. (2021) Repurposing waste plastics into cleaner asphalt pavement materials: A critical literature review. Journal of Cleaner Production 280, 124355, DOI: 10.1016/j.jclepro.2020.124355

10. Hopewell, J., Dvorak, R., Kosior, E. (2009) Plastics recycling: Challenges and opportunities. Philosophical Transactions of the Royal Society B 364, 2115–2126, DOI: 10.1098/rstb.2008.0311

11. (••) Turner, A. (2018) Black plastics: linear and circular economies, hazardous additives and marine pollution. Environment International 117, 308–318, DOI: 10.1016/j.envint.2018.04.036

This paper brightens an important issue: the risks that black plastics pose due to both technical and economic constraints. Constraints imposed on the efficient sorting (and separation) of black EoL plastics for recycling. This coupled with the occurrence of harmful additives necessary for black plastic production. This paper suggest as

sustainable option the use of lighter (preferably clear) coloured plastic when thermal stress is not a constraining factor.

12. Diggle, A., Walker, T.R. (2020) Implementation of harmonized Extended Producer Responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. Waste Management 110, 20–23, DOI: 10.1016/j.wasman.2020.05.013
13. European Commission (EC) (2018) A European Strategy for Plastics in a Circular Economy. COM/2018/028 final, 16.01.2018. European Commission, Bruxelles
14. Scalenghe, R. (2018). Resource or waste? A perspective of plastics degradation in soil with a focus on end-of-life options. Heliyon 4, e00941, DOI: 10.1016/j.heliyon.2018.e00941
15. OECD (2018) Improving Markets for Recycled Plastics Trends, Prospects and Policy Responses. OECD Publishing, Paris, DOI: 10.1787/9789264301016-en
16. Andreasi Bassi, S., Boldrin, A., Faraca, G., Astrup, T.F. (2020) Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste? Resources, Conservation and Recycling 162, 105030, DOI: 10.1016/j.resconrec.2020.105030
17. APE Europe (2021) Agricultural Plastics are Non-Packaging Plastics–Position Paper. APE Europe, Levallois-Perret, France
18. Galati, A., Sabatino, L., Prinzivalli, C.S., D'Anna, F., Scalenghe, R. (2020) Strawberry fields forever: That is, how many grams of plastics are used to grow a strawberry? Journal of Environmental Management 276, 111313, DOI: 10.1016/j.jenvman.2020.111313

Sorry for this self-quotation, we have not found other papers that provide this type of results, in particular, the subdivision of plastic waste by type of polymer. This paper highlights the following findings: (i) the total amount of plastic polymers used to produce one single kg of strawberries is 86 grams, (ii) the propensity of farmers geared towards recycling despite management difficulties although technical recyclability of plastic

feasible but not economically sustainable, and that (iii) for farmers, emerges a clear need for training and awareness raising.

19. Xiong, Y., Zhang, Q., Chen, X., Bao, A., Zhang, J., Wang, Y. (2019) Large scale agricultural plastic mulch detecting and monitoring with multi-source remote sensing data: A case study in Xinjiang, China. Remote Sensing 11, 2088, DOI: 10.3390/rs11182088
20. Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M. (2009) Philosophical Transactions of the Royal Society B 364, 1985–1998, DOI: 10.1098/rstb.2008.0205
21. Hahladakis, J.N., Velis, C.A., Weber, R., Iacovidou, E., Purnell, P. (2018) An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 344, 179–199, DOI: 10.1016/j.jhazmat.2017.10.014
22. (•) Gerritse, J., Leslie, H.A., de Tender, C.A., Devriese, L.I., Vethaak, A.D. (2020) Fragmentation of plastic objects in a laboratory seawater microcosm. Scientific Reports 10, 10945, DOI: 10.1038/s41598-020-67927-1

    This paper explores the behaviour in simulated seawater of fragments of different polymers, including HDPE, LDPE, PLA, PET, PS, PU. Key findings are that objects composed of polymers with a carbon–carbon "C–C" backbone, PE, PS and PP, are most recalcitrant with a maximum fragmentation rate of 1% per year, compared to 27% in the case of PLA.
23. Cox, J., Goldratt, E. M. (1986) The Goal: A Process of Ongoing Improvement. ISBN 0-88427-061-0. New York: North River Press.
24. Di Gioia, F., De Bellis, P., Mininni, C., Santamaria, P. and Serio, F. (2017) Physicochemical, agronomical and microbiological evaluation of alternative growing media for the production of rapini (*Brassica rapa* L.) microgreens. Journal of the Science of Food and Agriculture 97, 1212–1219, DOI:10.1002/jsfa.7852

25. Wu, S., Montalvo, L. (2021) Repurposing waste plastics into cleaner asphalt pavement materials: A critical literature review. Journal of Cleaner Production 280,124355, DOI: 10.1016/j.jclepro.2020.124355
26. Picuno, P. (2014) Innovative material and improved technical design for a sustainable exploitation of agricultural plastic film. Polymer-Plastics Technology and Engineering 53(10), 1000–1011, DOI: 10.1080/03602559.2014.886056
27. Sintim, H.Y., Bary, A.I., Hayes, D.G., Wadsworth, L.C., Anunciado, M.B., English, M.E., Bandopadhyay, S., Schaeffer, S.M., DeBruyn, J.M., Miles, C.A., P.Reganold, J.P., Flury, M. (2020) In situ degradation of biodegradable plastic mulch films in compost and agricultural soils. Science of the Total Environment, 727, 138668, DOI: 10.1016/j.scitotenv.2020.138668
28. Velandia, M., Galinato, S., Wszelaki, A. (2020) Economic evaluation of biodegradable plastic films in Tennessee pumpkin production. Agronomy 10(1), DOI: 51. 10.3390/agronomy10010051
29. Velandia, M., DeLong, K.L., Wszelaki, A., Schexnayder, S., Clark, C., Jensen, K. (2020) Use of polyethylene and plastic biodegradable mulches among Tennessee fruit and vegetable growers. HortTechnology 30(2), 212–218, DOI: 10.21273/HORTTECH04559-19
30. Chae, Y., An, Y.J. (2018) Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. Environmental Pollution 240, 387–95, DOI: 10.1016/j.envpol.2018.05.008
31. Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis. Science of the Total Environment 651, 484–92, DOI: 10.1016/j.scitotenv.2018.09.105
32. Qi, Y., Yang, X., Pelaez, A.M., Huerta Lwanga, E., Beriot, N., Gertsen, H., Garbeva, P., Geissen, V. (2018) Macro- and micro- plastics in soil-plant system: Effects of plastic

mulch film residues on wheat (Triticum aestivum) growth. Science of The Total Environment 645, 1048–1056, DOI: 10.1016/j.scitotenv.2018.07.229

33. EIP-AGRI Focus Group (2021) Reducing the Plastic Footprint of Agriculture – Final Report. The European Innovation Partnership 'Agricultural Productivity and Sustainability', pp. 1–36. European Commission, Bruxelles, EU

34. Picuno, C., Alassali, A., Sundermann, M., Godosi, Z., Picuno, P., Kuchta, K. (2020) Decontamination and recycling of agrochemical plastic packaging waste. Journal of Hazardous Materials 381, 120965, DOI: 10.1016/j.jhazmat.2019.120965

35. van den Berg, P., Huerta-Lwanga, E., Corradini, F., Geissen, V. (2020) Sewage sludge application as a vehicle for microplastics in eastern Spanish agricultural soils. Environmental Pollution 261, 114198, DOI: 10.1016/j.envpol.2020.114198

36. Rentizelas, A., Shpakova, A., Mašek, O. (2018) Designing an optimised supply network for sustainable conversion of waste agricultural plastics into higher value products. Journal of Cleaner Production 189, 683–700, DOI: 10.1016/j.jclepro.2018.04.104

37. Scarascia-Mugnozza G., Sica, C., Picuno, P. (2008). The optimisation of the management of the agricultural plastic waste in Italy using a Geographical Information System. Acta Horticulturae, 801, 219–226.

38. Briassoulis, D., Hiskakis, M., Babou, E., Antiohos, S.K., Papadi, C. (2012) Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential. Waste Management 32, 1075–1090, DOI: 10.1016/j.wasman.2012.01.018

39. Picuno, P., Tortora, A., Capobianco, R.L. (2011) Analysis of plasticulture landscapes in Southern Italy through remote sensing and solid modelling techniques. Landscape and Urban Planning 100, 45–56, DOI: 10.1016/j.landurbplan.2010.11.008

40. Jones, G. (2018) Recovering Agricultural Plastics: Obstacles and Opportunities. Available at https://wasteadvantagemag.com/recovering-agricultural-plastics-obstacles-and-opportunities/
41. Gopinath, K.P., Nagarajan, V.M., Krishnan, A., Malolan, R. (2020) A critical review on energy, environmental and economic factors on various processes used to handle and recycle plastic wastes: development of a comprehensive index. Journal of Cleaner Production 274, 123031, DOI: 10.1016/j.jclepro.2020.123031
42. Meng, T., Klepacka, A.M., Florkowski, W.J., Braman, K. (2016) Determinants of recycling common types of plastic product waste in environmental horticulture industry: The case of Georgia. Waste Management 48, 81–88, DOI: 10.1016/j.wasman.2015.11.013
43. Muise, I., Adams, M., Côté, R., Price, G.W. (2016) Attitudes to the recovery and recycling of agricultural plastics waste: A case study of Nova Scotia, Canada. Resources, Conservation and Recycling 109, 137–145, DOI: 10.1016/j.resconrec.2016.02.011
44. World Economic Forum (2016) The New Plastics Economy–Rethinking the Future of Plastics, pp. 1–36. World Economic Forum, Geneva, Switzerland
45. Horodytska, O., Valdés, F.J., Fullana, A. (2018) Plastic flexible films waste management–A state of art review. Waste Management 77, 413–425, DOI: 10.1016/j.wasman.2018.04.023
46. Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Munõz, K., Frör, O., Schaumann, G.E. (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? Science of the Total Environment 550, 690–705, DOI: 10.1016/j.scitotenv.2016.01.153
47. Clarke, S.P. (2000) Recycling Farm Plastic Films. Ministry of Agriculture, Food & Rural Affairs, Agriculture & Rural, Guelph, ON, Canada
48. Sinha, J., Sahu, R., Sahu, R.K., Nigam, G.K. (2019) Used plastic materials as mulches: An alternative to conventional black plastic mulch for small and marginal farmers.

Physics and Chemistry of the Earth, Parts A/B/C 109, 70–78, DOI: 10.1016/j.pce.2019.02.005

49. Dentzman, K.E., Goldberger, J.R. (2020) Organic standards, farmers' perceptions, and the contested case of biodegradable plastic mulch in the United States. Journal of Rural Studies 73, 203–213, DOI: 10.1016/j.jrurstud.2019.11.002
50. Meng, T., Klepacka, A.M., Florkowski, W.J., Braman, K. (2016) Determinants of recycling common types of plastic product waste in environmental horticulture industry: The case of Georgia. Waste Management 48, 81–88, DOI: 10.1016/j.wasman.2015.11.013
51. De Lucia, C., Pazienza, P. (2019) Market-based tools for a plastic waste reduction policy in agriculture: A case study in the south of Italy. Journal of Environmental Management, 250, 109468, DOI: 10.1016/j.jenvman.2019.109468
52. Pazienza, P., De Lucia, C. (2020) For a new plastics economy in agriculture: Policy reflections on the EU strategy from a local perspective. Journal of Cleaner Production 253, 119844, DOI: 10.1016/j.jclepro.2019.119844
53. European Commission (2015) Closing the Loop - An EU Action Plan for the Circular Economy, COM(2015)614. EC, Brussels, 2.12.2015, EUR-Lex Document 52015DC0614
54. European Commission (2018) European Strategy for Plastics in a Circular Economy, COM(2018)28. EC, Brussels, 16.1.2018, EUR-Lex Document 52018DC0028
55. Leal Filho, W., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., Voronova, V. (2019) An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. Journal of Cleaner Production 214, 550–558, DOI: 10.1016/j.jclepro.2018.12.256
56. Pazienza, P., De Lucia, C. (2020) The EU policy for a plastic economy: Reflections on a sectoral implementation strategy. Business Strategy and the Environment 29(2), 779–788, DOI: 10.1002/bse.2445

57. (••) Lau, W.W.W. *et* 28 *al*. (2020) Evaluating scenarios toward zero plastic pollution. Science 369, 1455–1461, DOI: 10.1126/science.aba9475

This paper compares total plastic demand under different EoL fates for year 2016 and for year 2040 under the Business as Usual and System Change scenarios. A key clue is that the complex composition of multi-material plastics limits the technical feasibility of sorting and reprocessing, decreasing the economic attractiveness of recycling.

58. (•) Borrelle, S.B. *et* 19 *al*. (2020) Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369, 1515–1518, DOI: 10.1126/science.aba3656

Because an environmentally acceptable threshold has yet to be defined this paper proposes a target scenario to reduce annual plastic emissions: 8 million metric tons (Mt). Among other issues, this paper discusses pros and cons of waste-to-energy processing.

59. Padhan, R.K., Sreeram, A. (2018) Enhancement of storage stability and rheological properties of polyethylene (PE) modified asphalt using cross linking and reactive polymer based additives. Construction and Building Materials 188, 772–780, DOI: 10.1016/j.conbuildmat.2018.08.155

60. (•) Eriksen, M.K., Pivnenko, K., Faraca, G., Boldrin, A., Astrup, T.F. (2020) Dynamic material flow analysis of PET, PE, and PP flows in Europe: Evaluation of the potential for circular economy. Environmental Science & Technology, DOI: 10.1021/acs.est.0c03435

This paper evaluates the potential circularity of PET, PE, and PP flows in Europe based on dynamic material flow analysis, considering product lifetimes, demand growth rates, and downcycling (quality reductions of recycled plastic).

FIGURE CAPTIONS

Figure 1 This paper describes plastic disposal and management options from the perspective of both economic and environmental aspects

Figure 2 Plastics in agriculture. Many plastic tools are fundamental in modern agriculture: bags for fertilizers, seeds, or feed, containers for agrochemicals and products, pipes for drainage and irrigation, nets, mesh, strings, ropes, trays, and many types of films. Each of these means of production is made with a specific polymer, for which EoL objects made of PE, PC, PMMA, PP, PS, and PVC are used.

Figure 3 Of the 17 Sustainable Development Goals (SDGs) of the United Nations, Goal 8 promotes sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. The theme of the circular economy and the recycling of materials must not ignore the quality of people's work and life. The unbridled rush of Western countries to recycle materials, with an eye to the quality of the local environment (as well as to profit), has led to exacerbation of the situation on a global scale. In 2018, China, the world's largest importer of EoL plastics, forbade the import of numerous categories of waste, including plastics. This image is from the movie *Plastic China* [courtesy of cnex.com.tw]

Figure 4 The 17 interlinked Sustainable Development Goals (A/RES/71/313 E/CN.3/2018/2) are an urgent call for action by all countries in a global partnership towards a shared blueprint for peace and prosperity for people and the planet, now and into the future. Objects constructed with plastic polymers, throughout their life cycle, are influenced by one or more crucial SDGs at each step.

Figure 1

Click here to access/download;Figure;Figure1.tif

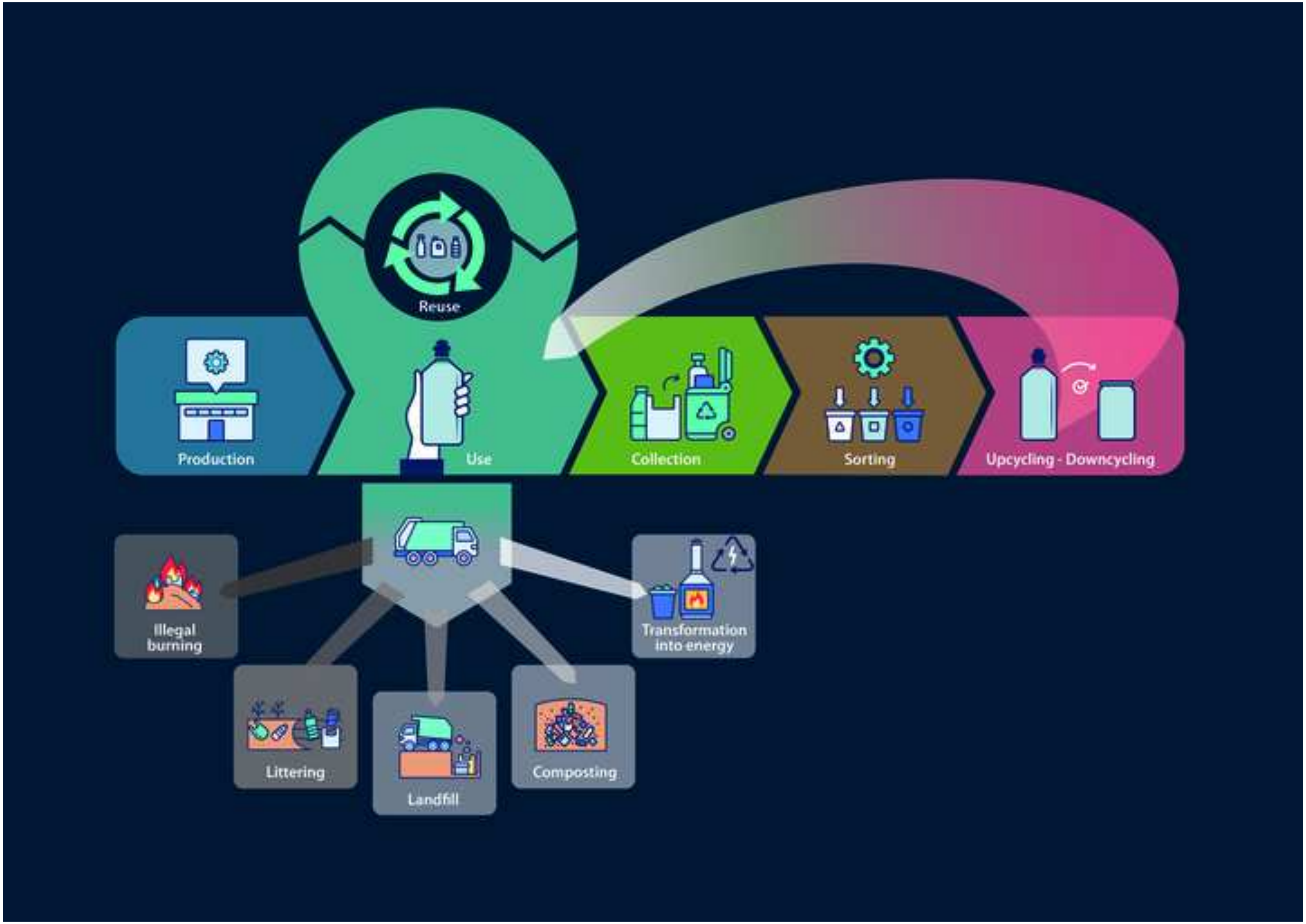


Figure 2

Click here to access/download;Figure;Figure2colore.tif

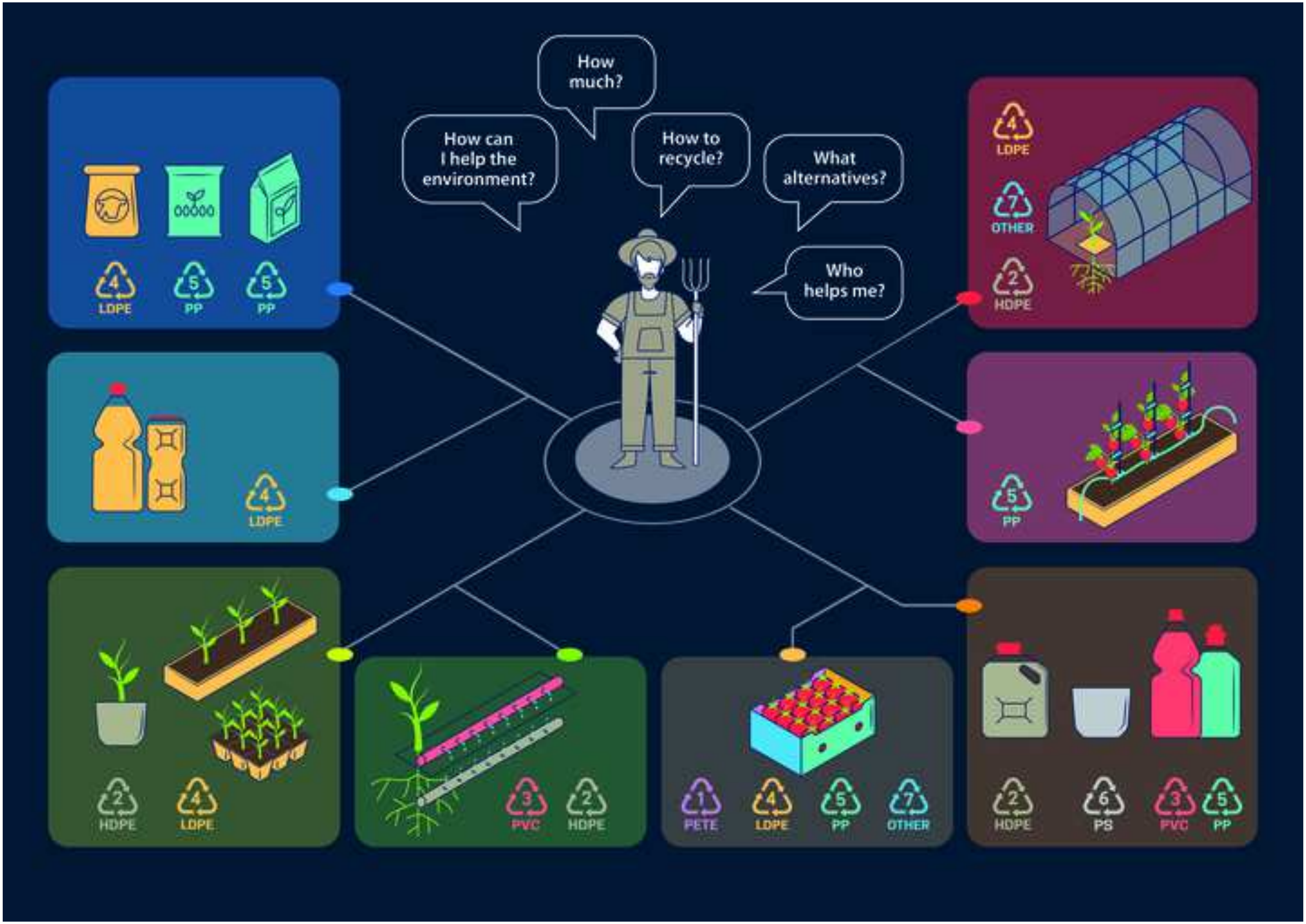
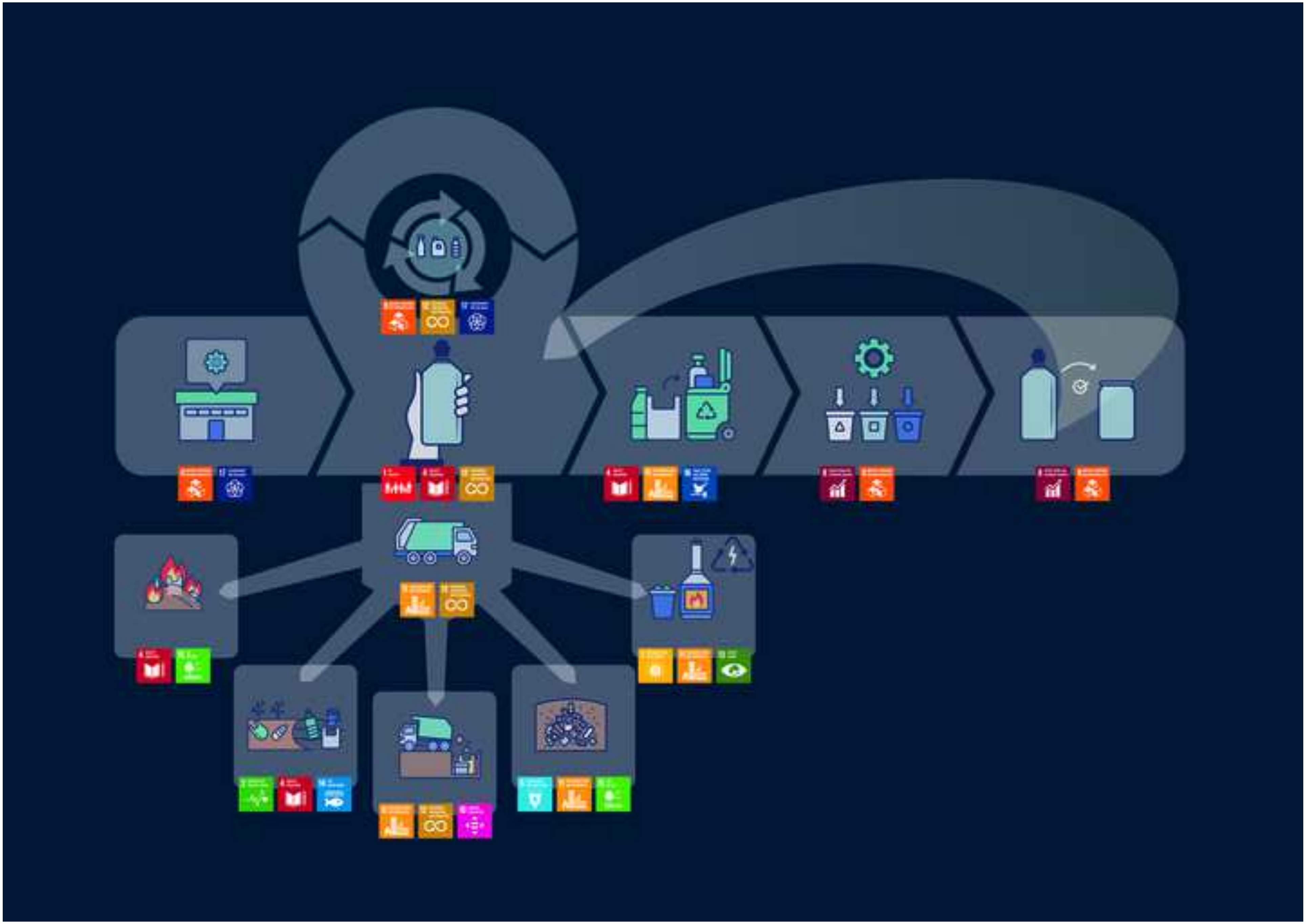


Figure 4

Click here to access/download;Figure;Figure4.tif



ID **COCHE-D-20-00043** "***Plastic end-of-life alternatives, with a focus on the agricultural sector***"

Dear Professor Cabezas,
Many thanks for your efficient and constructive management of our submitted manuscript.
We are re-submitting it revised taking into careful account all the received comments and suggestions. Below please find our replies to each point raised by the reviewers. Please note that based on one of these comments, we changed a bit the title to make it less competitive with other articles. Finally, some new fundamental references were added.
On an editable source file, we have highlighted all changes made to the original version of our manuscript for the reviewers to verify whether their observations were considered properly.
Following the reviewer's instructions, our revised manuscript currently consists of 3829 words and 61 quotes.

We thank you for substantially appreciating our contribution to your journal.
Antonino Galati and Riccardo Scalenghe

Reviewer: 1
The review paper by Galati and Scalenghe is rather simple. Only one small part of the paper is referring to agricultural plastic waste.
Response: We received an invitation in which was written: "*Dear Professor Scalenghe, On behalf of Heriberto Cabezas we would like to invite you to contribute a review article to the journal Current Opinion in Chemical Engineering in the Frontiers of Chemical Engineering section. The focus of the proposed issue will be on Plastics in The Environment. This issue will be edited by Heriberto Cabezas, University of Miskolc, Sadhan C. Jana, University of Akron, and Ramani Narayan, Michigan State University. Current Opinion in Chemical Engineering invites experts to develop short review articles which are meant not to review the literature (such reviews can be cited) or necessarily to be broad in scope, but rather to identify promising new areas and to stimulate future work, to be bold and perhaps even controversial. The articles are short, about 2500 words or 5-10 printed pages with figures and no more than 50 references and they focus on the past 2-5 years. The goal of the journal is to inform researchers, professionals, and students of the newest, most important publications on a given topic and to provide the reader with the views/opinions of the expert in each topic. Here is a link to the Guide for Authors for further formatting information. Our prosed topic for your review article would be "Plastic End-of -Life Options" or a related topic for the February 2021 issue. We would need to receive your article by December 31, 2020. We can discuss a deadline extension if necessary. Best Regards, Heriberto Cabezas, Sadhan C. Jana, Ramani Narayan*".
Afterwards, we received a further communication:"*Dear Dr. Scalenghe, Thank you very much for agreeing to prepare a short review article for the above referenced issue of Current Opinion in Chemical Engineering. This is the formal invitation to submit your article to this issue. Accepting this invitation will provide you with access to the journal's submission system, and (very importantly) will mean that your submitted article is linked to the correct issue.*
NUMBER OF WORDS: 2500 words: not including abstract, references and figure legends.
NUMBER OF FIGURES: Maximum of 4 additional elements (figures, boxes, tables)
ANNOTATED REFERENCES: The majority of the references (please aim to cite approximately 50) should come from the period under review (i.e. the past two years) and, in general, at least 10% of these should be selected and annotated as being papers of special interest (*) or outstanding interest (**). Annotated references MUST be from the past two years, and the annotation should provide a

brief description of the major findings and the importance of the study. This is an essential part of each review and is very popular with our readers. Kind regards, Genevieve Green-Editorial Manager, Current Opinion in Chemical Engineering".

To comply with these requests, which indeed are quite clear and stringent, we decided to propose a sectoral example by making the scope initially proposed, Plastic End-of -Life Options, a bit more restricted with an example. This is to follow the instructions for authors, 2500 words and 50 citations. In the original version we have managed to keep the number of citations to 45, so there is still a small margin to integrate with very recent literature. The number of words, in truth, was already in excess of 2500 words and, honestly, we expected a possible request for a reduction of some parts. Reading that our paper is "*is rather simple*" we find it rather offensive as we have spent a lot of time to be able to be updated, but above all respectful of the journal's stringent requests. Furthermore, the statement that "*only one small part of the paper is referring to agricultural plastic waste*" we do not think it is objective, since 32% of the space dedicated to the agricultural sector seemed excessive to us because of the initial request to write a review on the topic "Plastic End-of-Life Options". Reason why we don't know how to interpret these comments.

1. More literature review is required and should be added in the manuscript.

Response: As we specified in the previous answer, the space available to add new literature is rather limited but we certainly welcome the invitation with pleasure by adding quotes from several recent key sources.

A Focus Group of the European Commission on "How to reduce the plastic footprint in agriculture?" (EIP-AGRI Focus Group, 2021), recognising the main and most urgent needs, proposes the identification of the main use and properties of plastics in farming activities, including the identification of the indirect sources (van den Berg et al., 2020).

- EIP-AGRI Focus Group (2021) Reducing the Plastic Footprint of Agriculture‒Final Report. The European Innovation Partnership 'Agricultural Productivity and Sustainability', pp. 1–36. European Commission, Bruxelles, EU
- van den Berg, P., Huerta-Lwanga, E., Corradini, F., Geissen, V. (2020) Sewage sludge application as a vehicle for microplastics in eastern Spanish agricultural soils. Environmental Pollution 261, 114198, DOI: 10.1016/j.envpol.2020.114198

2. The plastic waste in agriculture sector plays an important role for the plastic waste input into the environment. This part is neglected from the manuscript and should be added.

Response: The available space is very limited. We accept the reviewer's invitation by adding a few key quotes.

The accumulation of plastic from agricultural activities raises concerns for soil health, macro- and micro- plastic residues have negative effects on both above-ground and below-ground parts of crops affecting both vegetative and reproductive growth (Chae and An, 2018; Gao et al. 2019; Qi et al. 2018). In particular, Gao et al. (2019) observed significant yield decrease starting from 240 kg ha^{-1} of plastic residues.

Plastic waste management is an additional cost that has to be covered: the EoL plastics collection and storage is a supplementary effort for farmers. However, an inappropriate collection and bad storage lead to contamination of the total environment (EIP-AGRI Focus Group, 2021). Plastic polymers must be robust enough to be simply collected without producing debris: an effective removal and collection of EoL plastics is critical to enable appropriate management (Picuno et al., 2020).

- Chae, Y., An, Y.J. (2018) Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. Environmental Pollution 240, 387–95, DOI: 10.1016/j.envpol.2018.05.008
- Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis. Science of the Total Environment 651, 484–92, DOI: 10.1016/j.scitotenv.2018.09.105
- Picuno, C., Alassali, A., Sundermann, M., Godosi, Z., Picuno, P., Kuchta, K. (2020) Decontamination and recycling of agrochemical plastic packaging waste. Journal of Hazardous Materials 381, 120965, DOI: 10.1016/j.jhazmat.2019.120965
- Qi, Y., Yang, X., Pelaez, A.M., Huerta Lwanga, E., Beriot, N., Gertsen, H., Garbeva, P., Geissen, V. (2018) Macro- and micro- plastics in soil-plant system: Effects of plastic mulch film residues on wheat (*Triticum aestivum*) growth. Science of The Total Environment 645, 1048–1056, DOI: 10.1016/j.scitotenv.2018.07.229

3. The policy measurements are not included as well. The use of new (biodegradable) materials or PE films in agricultural sector should be described in more details.
Response: We are grateful to the reviewer for your suggestions according to which we improved the manuscript better emphasizing the opportunity offered by alternative and more sustainable materials such as the biodegradable film.

Alternatively, new materials have been developed in recent years to address the unsustainability of both traditional plastic materials and some recycling processes adopted. Among these, biodegradable or oxo-degradable plastics, that at the end of their life can be buried in the soil or alternatively composted on farm, allowing to overcome environamental and disposal problems (Picuno, 2014). Comparing these two alternatives, Sintin and colleagues (2020) find that the degradation process is faster in the form of compost than through burial. The use of biodegradable plastics does not only produce an environmental but also an economic benefit. Velandia and colleagues (2020a) comparing the use of PE and BP film in Tennessee Pumpkin production, find that the use of bio-degradable films, in the face of a higher price, entails a sensitive improvement in the profit due to a reduction of the labour cost associated with the PE mulch removal and disposal. The price of biodegradable films and the cost of labour are two important discriminants in the transition process from the use of PE and those of biodegradable plastics. A recent study on the farmers willingness to pay for biodegradable films in relation to the market price shows that farmers' willingness to pay decreases as the market price increases (Velandia et al., 2020b).

- Velandia, M., Galinato, S., Wszelaki, A. (2020) Economic evaluation of biodegradable plastic films in Tennessee pumpkin production. Agronomy 10(1), DOI: 51. 10.3390/agronomy10010051
- Velandia, M., DeLong, K.L., Wszelaki, A., Schexnayder, S., Clark, C., Jensen, K. (2020) Use of polyethylene and plastic biodegradable mulches among Tennessee fruit and vegetable growers. HortTechnology 30(2), 212–218, DOI: 10.21273/HORTTECH04559-19
- Sintim, H.Y., Bary, A.I., Hayes, D.G., Wadsworth, L.C., Anunciado, M.B., English, M.E., Bandopadhyay, S., Schaeffer, S.M., DeBruyn, J.M., Miles, C.A., P.Reganold, J.P., Flury, M. (2020) In situ degradation of biodegradable plastic mulch films in compost and agricultural soils. Science of the Total Environment, 727, 138668, DOI: 10.1016/j.scitotenv.2020.138668
- Picuno, P. (2014) Innovative material and improved technical design for a sustainable

- exploitation of agricultural plastic film. Polymer-Plastics Technology and Engineering 53(10), 1000–1011, DOI: 10.1080/03602559.2014.886056

In addition, we briefly introduced the current strategy adopted by the EU in order to bridge the issue of plastic materials in the agricultural sector.

To date, there is no and European regulation on the management of agricultural plastic waste, rather a general strategy that emerged already in 2015 with the adoption by the European Commission of the "Action Plan for the Circular Economy" (COM(2015)614), and subsequently in 2018 with the Communication COM (2018)28 on "European Strategy for plastics in a circular economy". With this latest communication, the Commission outlined the EU strategy to guide the transition to a more circular plastics economy in the near future by providing specific measures. With reference to agricultural plastics, the Commission suggests to national authorities and industries to introduce Expected Producer Responsibility (EPR) in order to provide incentives for plastic recycling (Annex II) which, as suggested by Filho and colleagues (2019), is the most effective measure that can contribute more to the achievement of EU objectives also in the agricultural sector. The Commission also proposes as key measures a better use of taxation or other economic instruments to improve the quality of recycling. Some recent studies analyzed the acceptability by farmers of some policy measures that could encourage a more farmers' responsible behavior, including subsidies, tax credit, and pay-back under EPR scheme (Picuno and Pazienza, 2020a; Picuno and Pazienza, 2020b). The authors find that tax credit is the most favored tool among farmers, particularly in large farms, probably due to the complexity and costs associated with the waste management system, while for small and medium-sized farms pay- back EPR scheme. This finding underlines the importance of defining adequate and targeted policy tools in relation to the characteristics of the companies and for an effective implementation of the European strategy.

- European Commission (2015) Closing the Loop - An EU Action Plan for the Circular Economy, COM(2015)614. EC, Brussels, 2.12.2015, EUR-Lex Document 52015DC0614
- European Commission (2018) European Strategy for Plastics in a Circular Economy, COM(2018)28. EC, Brussels, 16.1.2018, EUR-Lex Document 52018DC0028
- Leal Filho, W., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., Voronova, V. (2019) An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. Journal of Cleaner Production 214, 550–558, DOI: 10.1016/j.jclepro.2018.12.256
- Pazienza, P., De Lucia, C. (2020) For a new plastics economy in agriculture: Policy reflections on the EU strategy from a local perspective. Journal of Cleaner Production 253, 119844, DOI: 10.1016/j.jclepro.2019.119844
- Pazienza, P., De Lucia, C. (2020) The EU policy for a plastic economy: Reflections on a sectoral implementation strategy. Business Strategy and the Environment 29(2), 779–788, DOI: 10.1002/bse.2445

4. The paper should be focused on plastic materials used in the field, not for packaging fruits or vegetables, because this usually takes place off-site (and it is considered post-consumer plastic waste).

Response: We are grateful to the reviewer for this comment according to which we revised the manuscript by focusing on plastic materials used by farmers in the field. Some example in the text to plastics used in other sectors have been included in order to remark the need to identify effective

strategy to support the transition towards a economy of plastic in line a with the circular economy paradigm. We also added a specific quote on EPR:
“APE Europe, the professional representative body of plastics for agriculture in Europe, states that agri-plastics can only be considered as non-packaging plastics invoking specific Extended Producer Responsibility framework in EoL management (APE Europe, 2021)”

- APE Europe (2021) Agricultural Plastics are Non-Packaging Plastics–Position Paper. APE Europe, Levallois-Perret, France

Revised MS tracking changes

Click here to access/download
Supplementary Material
Main Document_Revised_trackingchanges.docx

Credit Author Statement

All authors contributed to conceptualization, data curation, formal analysis, methodology, project administration, visualization, writing the original draft as well as review & editing.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: