Conventional and Biodegradable Plastics in Agriculture

For the European Commission DG Environment. Project conducted under Framework Contract No ENV.B1/FRA/2018/0002 Lot 1

July – 2021

Luxembourg: Publications Office of the European Union, 2021

Relevance of Conventional and Biodegradable Plastics in Agriculture

Final Report

Simon Hann
Emma Fletcher
Star Molteno
Chris Sherrington
Laurence Elliott
Mary-ann Kong (Deloitte)
Alima Koite (Deloitte)
Sergio Sastre (ENT)
Veronica Martinez (ENT)

26th July 2021

Report for DG Environment of the European Commission

Approved by

…………………………………………………….

Chris Sherrington

(Project Director)

Eunomia Research & Consulting Ltd
37 Queen Square
Bristol
BS1 4QS

United Kingdom

Tel: +44 (0)117 9172250
Fax: +44 (0)8717 142942

Web: www.eunomia.co.uk

Disclaimer

Abstract

A comprehensive EU Plastics Strategy has laid the foundations to a new circular plastics economy where plastic materials are kept in the loop as long as possible by promoting reuse and repair, remanufacturing, recycling and prevention of plastic waste.

The new Circular Economy Action Plan adds that a policy framework on the use of biodegradable plastics will be developed, based on an assessment of the applications where such use can be beneficial to the environment.

This study first seeks to quantify current levels of consumption, separate collection and flows through different end-of-life management routes of each category of agri-plastics in the EU. An analysis is undertaken of the problem drivers associated with improper collection, low reuse and recycling of *conventional* agri-plastics, and the technical and non-technical barriers impeding higher recycling and reuse rates. A similar analysis is also undertaken in respect of biodegradable agri-plastics. A business-as-usual baseline out to 2040 is determined, followed by identification of objectives and policy measures.

Following screening of policy measures, the retained options are assessed qualitatively and quantitatively, with recommendations for the Commission in terms of measures to be implemented, along with future research requirements. In general, the choice between the use of conventional and biodegradable plastics in agriculture will depend upon the local collection situation and the grower's requirements.

Executive Summary

This report has been prepared for DG Environment of the European Commission by Eunomia Research & Consulting Ltd and its partners, Deloitte and ENT.

The overall objective of this study, as per the Terms of Reference (ToR), is:

> *To support the Commission's work on potential policy actions regarding agricultural plastics, and regarding the establishment of a framework for biodegradable plastics.*

The ToR further states that:

> *In particular, the objective of the study is to identify and reduce the environmental impacts associated with conventional and biodegradable agricultural plastics. The main focus will be on their end-of-life, in particular their improper collection and their low reuse and recycling on the one hand and their effective biodegradability on the other hand. The study deals with those agricultural macro-plastics that are deliberately placed in the environment to fulfil a function in the agricultural system (including in horticulture and forestry).*

E.1.0 Approach

Extensive research was conducted to seek to understand the current state-of-play for agri-plastics across the EU (including desktop research and a number of semi-structured interviews with stakeholders). Following this, the Better Regulation Toolbox methodology was followed to identify problem drivers, and from these, to develop specific policy objectives to improve the management of agri-plastics at their end-of-life. Shortlisted policy measures were then modelled to understand the associated costs and benefits.

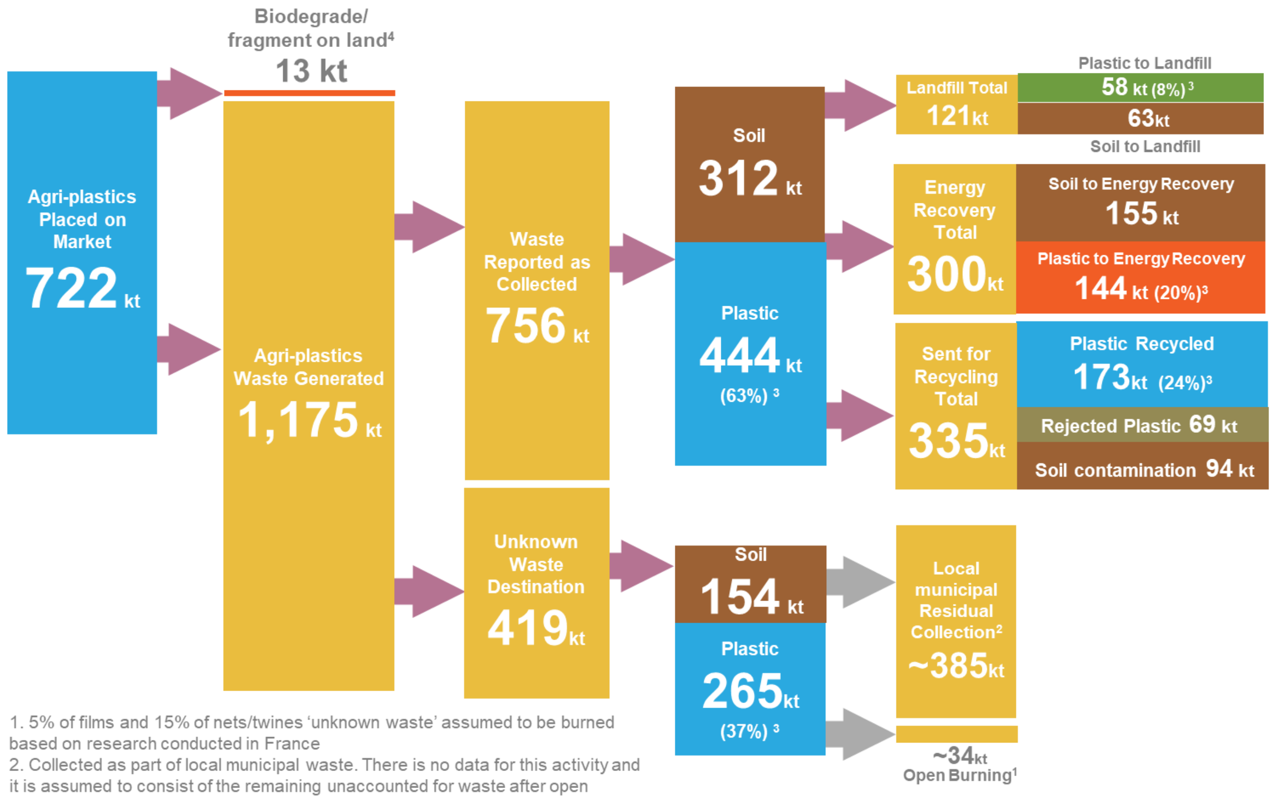
It is important to note that statistical reporting of agricultural plastics data in Europe is still relatively undeveloped. This has necessitated the use of carefully considered estimates and assumptions for some data inputs and modelling parameters. Data caveats are highlighted where necessary throughout the report.

E.2.0 Key Findings

E.2.1 Quantifying Agri-Plastics Consumption and End-of-Life Practices

Around 63% of agri-plastic non-packaging waste generated in the EU was reported as collected in 2019 by APE Europe. The fate of the remaining 37% of agri-plastics is not known – as by definition this is not recorded – but the agri-plastics may be stored, burnt, buried, or collected with another waste stream. Anecdotal estimates suggest that around 5% of the remaining material is burned and much of the rest is collected through local municipal waste schemes with the likely destination being residual treatment (see Figure E- 1). Countries with a well-established national collection scheme such as Ireland, Iceland, Norway, Sweden, France, and Spain have achieved a high collection rate reaching more than 70%. Furthermore, despite most agri-plastics having a high potential for recycling (being homogenous in nature and often separately collected), it is estimated that only 24% of the non-packaging agri-plastic waste placed on the market annually in the EU is currently recycled. Yields vary significantly by type of agri-plastic, with no reports of recycling taking place for mulch films and bale nets at present. Conversely, the collection and recycling of greenhouse films is relatively well established due to the high quality and comparatively less contaminated nature of this type of agri-plastics. The underlying data show that the plastic placed on the market only accounts for 60% of the waste generated, with the remainder being soil and other organic matter. This level of contamination is unique to agri-plastics and, as discussed in subsequent sections, is a leading cause of the low reported recycling rates. This soil contamination is estimated to be around 467 kt per year in the EU, with 36% (166 kt) of this arriving from mulch film collection despite only accounting for 12% of the market (by mass). The removal of soil from fields contributes to the loss of soil organic carbon (SOC) – a key component of soil health.

Figure E- 1: Agricultural Plastic EU Waste Mass Flow



1. 5% of films and 15% of nets/twines 'unknown waste' assumed to be burned based on research conducted in France
2. Collected as part of local municipal waste. There is no data for this activity and it is assumed to consist of the remaining unaccounted for waste after open burning.
3. Proportion relative to the total amount placed on the market (722kt)
4. Includes biodegradable mulch films certified to EN17033 and fragmenting oxo-degradable plastics that are restricted in the EU as of 3 July 2021.

E.2.2 Aspects of End-of-Life of Conventional Agri-Plastics

The challenges related to managing conventional agri-plastics at their end-of-life have been explored. The focus was on two inter-related issues: barriers to the separate collection of agri-plastic waste, and, once collected, barriers to its recycling.

E.2.2.1 Barriers to Collection

The main barriers to the separate collection of agri-plastics for recycling across the EU are:

- **Technical characteristics of mulch films which may mean it is difficult to completely remove the film from the soil without it tearing (and fragments subsequently remaining in the soil)**. Very limited data exists on this topic. Any estimate of the percentage of mulch films that remain in the soil in Europe are based on expert opinion, rather than collected data, and should be treated with caution.
- **Insufficient economic and / or regulatory incentives for the separate collection of agri-plastic waste**. Most agri-plastic products – with a few exceptions – do not have a positive value for recyclers, and therefore there is little economic incentive for waste managers to collect it separately. Furthermore, though the separate collection of plastic waste, and thus also agri-plastics, is required by law, the implementation of this requirement is not sufficient across the EU.

And where a separate collection scheme exists:

- **Insufficient awareness among farmers of schemes in existence.** For example, the scheme operator for ERDE (the German agri-plastics collection scheme) suggests that insufficient awareness among farmers is the reason for current, relatively low, rates of collection (~40%); the scheme was launched in 2013.
- **Insufficient incentives for farmers to participate in the separate collection of agri-plastic waste.** For example, farmers may choose to burn their agri-plastic waste on site or drip feed into the household waste stream, especially for low volume agri-plastics such as netting and twine which may be relatively easy to discretely include within the household waste stream.

E.2.2.2 Barriers to Recycling

The main barriers to recycling agri-plastics in the EU are:

- **High processing costs primarily due to high contamination rates**. For example, stakeholders suggest that even with the best practices applied, a contamination rate of 30% to 40% for mulch films is to be expected.
- **Low value / limited end markets for recyclate.** The quality of pellet produced from agri-plastics is in general relatively poor (the main exception to this is greenhouse films).

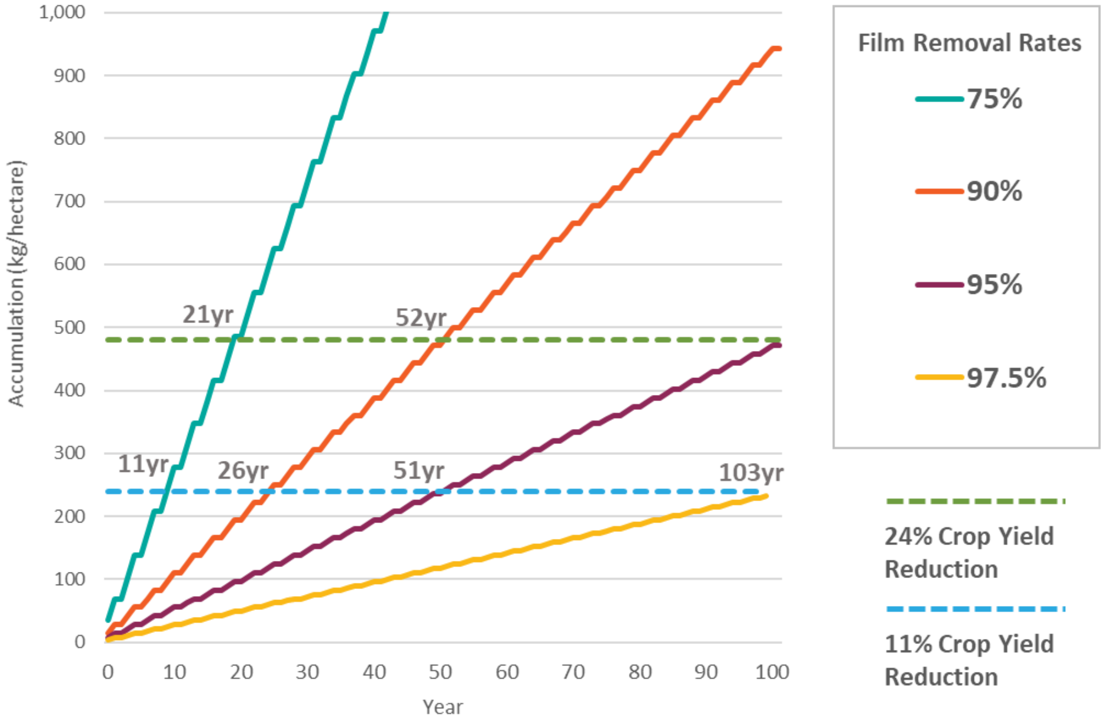
E.2.2.3 Environmental Impacts of Improper Collection

The improper collection of agri-plastics is likely to lead to negative environmental impacts and there is a greater chance that plastic residue will enter and remain in soil if it is not collected; although the exact fate of such residues is yet to be mapped, it is also possible that these could be transported into other environments.

Whilst specific research into the environmental impacts of agri-plastic residue in soil is neither expansive nor conclusive the following observations can be made:

- The existing scientific evidence base relies on examples from outside of the EU, but results indicate that if concentrations reach a certain threshold, negative impacts on soil fertility and crop yield are likely.
- Modelling conducted as part of this study looking at likely scenarios for the use of conventional mulch film found that such thresholds could be met within 11-51 years if 5-25% of the film is not removed from the soil after use (see Figure E- 2). To put this into context; **if 5-25% mulch film remaining is averaged across the EU, the annual use of 83,000 tonnes of mulch film would result in 4,750 -20,750 tonnes of conventional plastic remaining on agricultural land every year.**
- The proportion of conventional plastic mulch films that are typically left remaining is not known (figures in the range of 5-25% are often quoted, but the root of these have no direct link back to a published scientific study). There is no demonstrable link between common practice resulting in a particular proportion being left on the field. It is also unclear what is achievable if best practice is employed and to what extent technological improvements in field removal machinery could achieve. Anecdotal evidence suggests thicker films will result in less residue, but further study is required to determine the exact thickness (and therefore strength specification) that would be required.
- Low collection rates also increase the likelihood of agri-plastics being burned in the open. This practice is associated with the release of by-products which have a significant potential to contribute to global warming, as well as negative impacts on human health.

Figure E- 2: Conventional Plastic Mulch Film Accumulation Model



Source: Eunomia modelled calculations

E.2.3 Aspects of End-of-Life of Biodegradable Agri-Plastics

Biodegradable plastics are those that can be decomposed by the action of living organisms e.g. microbes into water, carbon dioxide, and biomass. Biodegradable plastics are commonly produced with renewable raw materials, micro-organisms, petrochemicals, or combinations of all three. The main focus of this report is on biodegradable mulch (BDM) films as they are the only biodegradable agri-plastics that have been subjected to extensive field studies and have a European product standard that is available to certify performance (EN 17033). Whilst the evidence base is focused on these products, the important aspects can be transferred to understand the implications of more widespread use in other product types.

E.2.3.1 Conclusions on Environmental Risk

Assessing the possible environmental impacts of BDMs is critical to evaluating their potential as a substitute for conventional plastics in agriculture. The review of evidence has shown that:

- *During use*, the effects of BDMs on soil health are comparable to the effects of conventional mulches although there is a learning process for the grower when transferring from conventional to BDMs to achieve optimum performance. This is not seen as a barrier if appropriate training and support is provided by the film supplier (which is typically the case).

- As full biodegradation of BDMs once tilled into the soil can take more than one year, the material can begin to accumulate in the soil in places where the average soil temperature is <15°C but this stabilises at a low level;
- Once application of BDMs ceases or if a fallow year is included, the presence of BDMs in the soil is likely to rapidly decrease (within 1-2 years) to zero in temperate climates (soil temperature >10°C); this is in contrast with conventional plastic which will remain at the same concentration.
- When using life cycle assessment (LCA) as a tool to compare environmental impact, current evidence suggests that conventional mulch films have a lower environmental impact compared with BDMs under most impact categories. Incorporating recycled material in conventional films increases the number of impact categories where BDMs are outperformed. However, the occurrence and negative impacts associated with residual conventional mulch film remaining on the field are not yet possible to be comparatively quantified.
- Biodegradable mulch films are likely to reduce the occurrence and persistence of plastics in the open environment, but this is a trade-off that is not possible to capture through typical LCA methodologies at present, and biodegradation pathways of biodegradable plastics in soil still have to be completely understood.
- The extent to which either conventional mulch films or BDM films may leach into waterways or other habitats has not been the subject of any specific study. If leaching or wind transportation does take place for conventional film fragments there is existing evidence to suggest there would be several (but as yet unquantifiable) negative ecosystem impacts. For BDMs, the impacts are likely to be comparatively less, but as aquatic biodegradation testing is not typically conducted on these materials, there is no guarantee that the impact would be zero.

Table 4-3 summarises the key trade-offs between conventional and BD mulch films. It highlights the considerable unknowns that prevent definitive conclusions at this time. Whilst conventional mulch films, once recycled, are thought to have lower overall life cycle environmental impact than BDMs, recycling does not typically take place primarily due to the high levels of contamination. Although it may be possible to incentivise recycling of collected material, further research is required to determine whether it is possible to consistently remove all traces of conventional film from the field after use. If this is not possible then a key trade-off of plastic pollution in the environment vs greenhouse gas emissions (as well as most other environmental impact categories) exists. If changes in technology improve removal and provide cleaner material into the recycling system this will provide a stronger case for continuing to use conventional mulch films. Advances in the production of bio-based feedstocks that reduce the environmental impacts of the raw materials may also affect whether this practice is more preferable in future. **Given this lack of certainty at the moment, it is important to have both options available, with the choice of which to use depending upon the local collection situation and the grower's requirements.**

Table E- 1: Summary of Mulch Film Material Environmental Trade-offs

Green = most favourable environmental scenarios; **Yellow** = mixed or uncertain scenarios;

Red = least favourable environmental scenarios

<table>
<tr><th>Trade-off >>
Mulch Material[5]</th><th>Raw Materials and Production</th><th>Landfill</th><th>Incineration</th><th>Left in Soil</th><th>Recycling</th></tr>
<tr><td>Bio-based biodegradable</td><td rowspan="2">Generally higher impact than conventional[1]</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td><td>Releases biogenic CO_2; ~1/3 is converted to biomass[1]</td><td rowspan="2">Does not take place - material value is lost</td></tr>
<tr><td>Fossil-based biodegradable</td><td>Releases fossil CO_2; ~1/3 is converted to biomass[1]</td></tr>
<tr><td>Bio-based Conventional</td><td rowspan="2">Generally lower impact than biodegradable</td><td rowspan="2">Inert, but possibility of methane from organic residues</td><td>Releases biogenic CO_2</td><td rowspan="2">Persists[4]</td><td rowspan="2">Material is recyclable[3]</td></tr>
<tr><td>Fossil-based Conventional</td><td>Releases fossil CO_2</td></tr>
</table>

1. It should be noted that this may change as supply chains and manufacturing processes develop over time.
2. It is unclear exactly which proportions are converted to CO_2 or biomass. An indicative figure of 1/3 conversion to biomass similar to that of compostable plastics is provided.
3. Recycling of mulch films in the EU is not typically undertaken – future improvements to collection rates and policy options that encourage recycling are required.
4. It is unclear how much residual plastic typically remains in the field (due to improper removal or thinner films tearing) at this time
5. Materials can also be a combination of fossil and bio-based. This means both fossil and biogenic CO_2 can be released from the same product depending upon circumstances.

E.2.3.2 Proposing Criteria for the Use of Biodegradable Agri-Plastics

It is clear that BDMs offer the grower an additional choice with benefits that are compelling. The results of this study do not give reason to legislate to prevent these from being used. However, new materials are being developed and new applications are being suggested for BDAPs such that there is a need for a set of principles that can guide the use of these products toward applications where a genuine benefit can be achieved and prevent misuse and false claims.

Table E- 2 summarises proposed criteria that should ideally be fulfilled in order to reduce environmental risks (recognising that this is focused on comparative risk) whilst respecting the waste hierarchy and focus on circular economy principles.

There are two tiers of criteria; primary and secondary. The primary tier consists of criteria that represent constants that are unlikely to change over time and should be fulfilled before the secondary criteria are addressed. Secondary criteria are evidence-based criteria that can be investigated for products/applications that meet the primary criteria. This aims to conserve resources that might be spent on product development, biodegradation testing and standard development for unsuitable applications.

Table E- 2: Criteria for Biodegradable Plastic Applications in Agriculture

Primary Tier
The use of conventional plastic results in negative environmental impacts associated with soil accumulation/ leakage into environment
The product cannot feasibly be removed, collected and disposed of responsibly, leaving no residues at the end of life
Secondary Tier
Similar or improved product specification and performance compared with the conventional alternative during use can be achieved
In-situ testing has been conducted to observe the biodegradation time expected in a particular climate
A standard test method and biodegradation threshold is available (e.g. EN 17566 and EN 17033)*
*EN 17566 is a generic in-soil biodegradation test method. EN17033 specifies the time limit and biodegradation threshold that this test should meet for mulch films. Both are required for a particular environment and product type, but tests do not exist for all environments currently.

Table E- 3 takes these criteria and applies them to the common agricultural plastic applications identified in this report as well as some niche and/or novel example applications. The results show that only mulch films are considered to be a suitable application for biodegradable materials at this time, which is consistent with the findings of the research for this report. The evidence base is strong for this application and it is the only one that can be verified through the use of a standard. At the other end of the scale, both silage wraps and greenhouse films fail on the primary criterion that collection cannot be achieved (as these can feasibly be collected). Whilst products such as greenhouse films are not being promoted by biodegradable plastics producers this provides a framework that justifies continuing that position.

Without a way of testing and verifying open environment biodegradation (and the difficulty of doing so), the focus should be on effective implementation of schemes (e.g. EPR) that make a compelling case for farms to collect and manage all plastic waste appropriately.

For products that can often be left in the environment, such as tree-protection, there is an argument for the use of biodegradable materials to reduce the impact —even if full biodegradation is not always achieved because of the particular conditions, it may be a better alternative to conventional plastic remaining forever. However, the lack of standardisation and certification for products other than BDMs makes it impossible to differentiate between products made from materials with an evidence base for biodegradation and ones that do not perform as claimed. It is clear that standardisation is critical in creating a level playing field and preventing false claims.

Table E- 3: Applying Criteria for BD Plastic Applications in Agriculture

✓= fulfils criterion, ✗ = fails criterion, ✓✗ = evidence base is unclear/or being developed

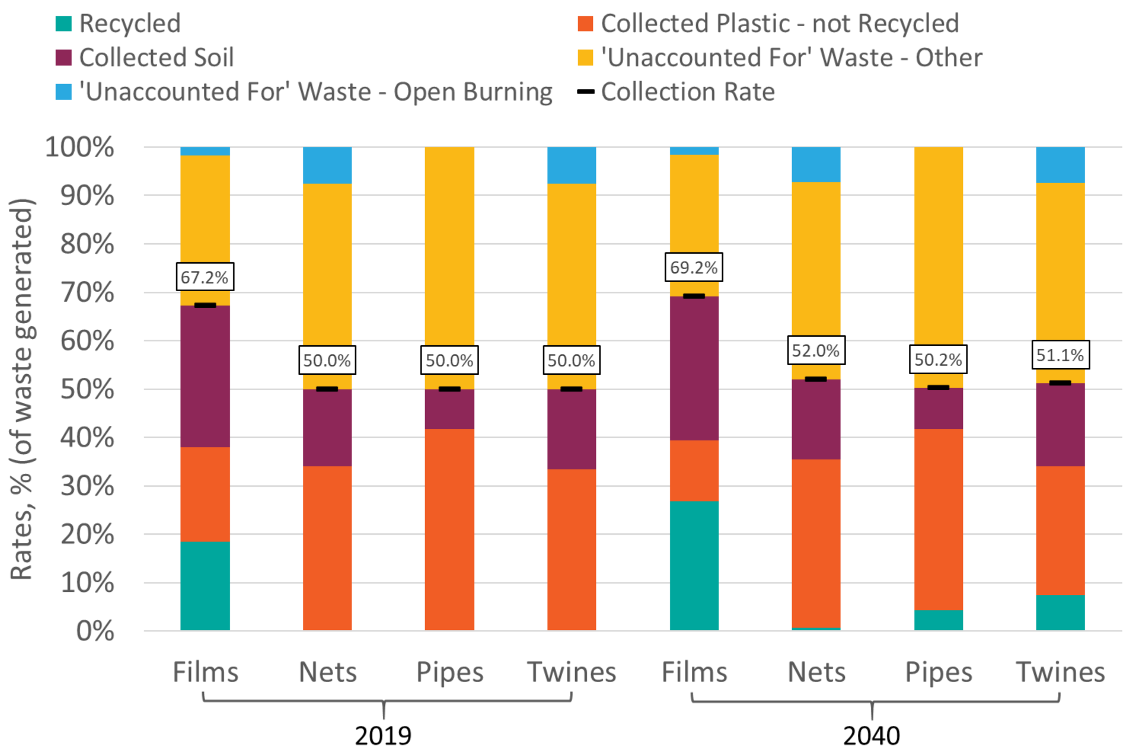
Criteria	Mulch Films - short cycle crop	Mulch film for rice production	Irrigation Drip Tape	Tree Protection	Twines and Nets	Silage Wraps	Greenhouse Films
Primary Criteria							
The use of conventional plastic results in negative environmental impacts associated with soil accumulation/ leakage into environment	✓	n/a	✓✗	✓	✓	✓	✓
The product cannot feasibly be removed, collected and disposed of responsibly, leaving no residues at the end of life	✓	✓	✓✗	✓✗	✓✗	✗	✗
Secondary Criteria							
Similar or improved product specification and performance during use can be achieved	✓	n/a	✗	✓	✓✗	✗	✗
In-situ testing has been conducted to observe the biodegradation time expected in a particular climate	✓	✓✗	✗	✗	✗	✗	✗
A standard test method and biodegradation threshold is available	✓	✓✗	✗	✗	✗	✗	✗

E.2.4 Baseline of Agri-Plastics Consumption, Waste Generation and Management

A baseline of agri-plastics consumption, waste generation and waste management routes in the EU28 was modelled and is presented in Section 5.0. It is anticipated that in the absence of further interventions there will be limited growth in the collection and recycling of conventional agri-plastics (see Figure E- 3). Therefore, it is recommended that the European Commission takes action to improve the end-of-life management of conventional agri-plastics.

The final destinations of waste generated for 2019 (latest year of historic data) and 2040 (final year of projections) are presented in Figure E- 3. Collection rates are shown as a black bar (and remaining waste – in yellow - is 'unaccounted for'). Of this collected waste, the purple fraction is soil (not recycled). Prior to final recycling, further losses of plastic waste are shown in orange. Final waste recycled is shown in green. Please note that this is a recycling rate based on waste generated (including soil), whilst recycling rates quoted in this report are based on recycled plastic as a % of plastic placed on the market (i.e. not including soil in collected waste).

Figure E- 3: Final Destinations of Agri-Plastic Waste in the EU28, Thousand Tonnes (2019, 2040)



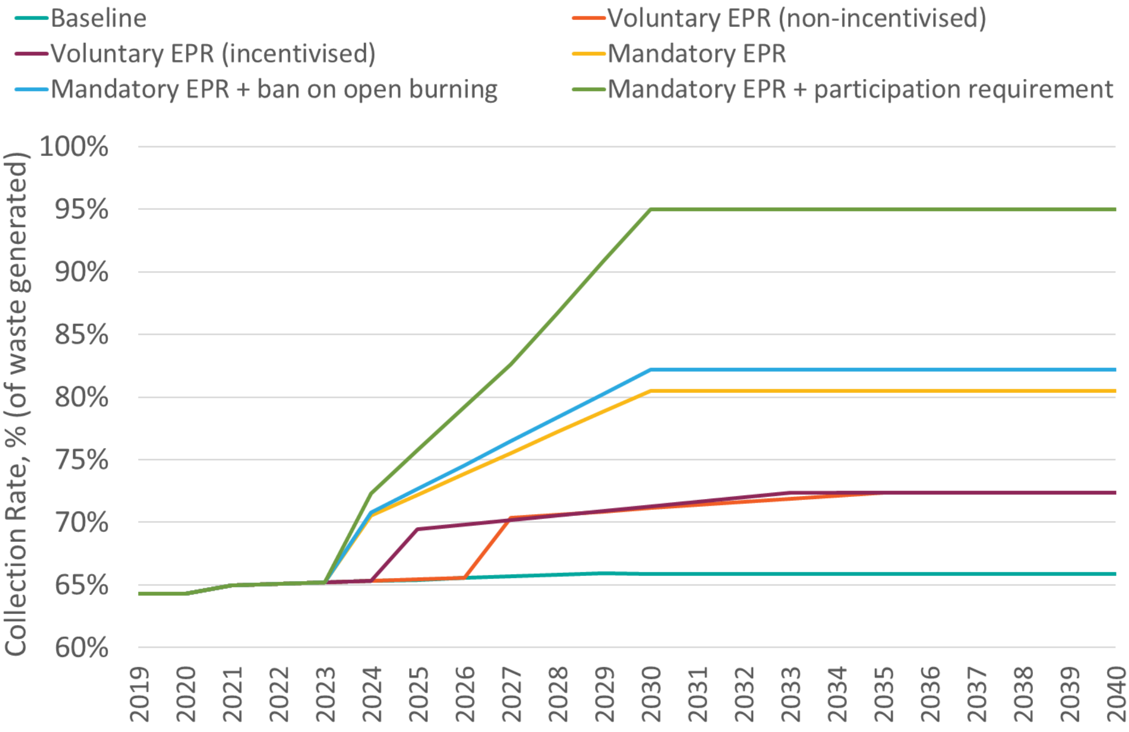
E.2.5 Policy Options

Based on the barriers to collection and recycling of conventional agri-plastics identified, and the assessment of the environmental risk of BDAPs at their end-of-life, a number of policy options were shortlisted and evaluated (see Section 6.0). The key findings relating to Extended Producer Responsibility (EPR) and supporting measures are as follows:

- The implementation of EPR for agri-plastics is likely to lead to significant improvements in the collection and recycling rate for agri-plastics across the EU. As a policy measure it is proportionate and targeted. It will also enable Member States to achieve the separate collection requirement for plastic waste, as set out in the Waste Framework Directive (WFD), and for which the 2015 deadline has already passed.
- There are three options considered for the implementation of EPR: mandatory; voluntary (incentivised) and voluntary (non-incentivised). Mandatory EPR is likely to be most effective. There are examples of successful voluntary agri-plastic EPR schemes (e.g. ADIVALOR in France) but it is anticipated that voluntary approaches may struggle to achieve the highest collection rates.
- The cost of waste management increases relative to the baseline for all EPR options due to a reduction in the volume of 'unaccounted for' waste (i.e. the waste that is not reported as collected through an agri-plastics collection scheme). Under EPR, more of this previously 'unaccounted for' waste is collected and therefore incurs waste management costs.
- EPR can be combined with other measures in order to further increase its effectiveness (e.g. a ban on open burning of agri-plastics or a requirement for farmers to participate in a separate collection scheme).

Figure E- 4 shows the modelled collection rates out to 2040 under the business-as-usual baseline, voluntary EPR (both incentivise and non-incentivised), and mandatory EPR. Higher collection rates are modelled where mandatory EPR is combined with supporting measures – a ban on open burning of agri-plastic waste, and a mandatory requirement for farmers to participate in agri-plastics collection schemes.

Figure E- 4: Modelled Collection Rates (2019 to 2040), %



E.3.0 Recommendations

E.3.1 EPR

Given the existing requirement for separate collection of plastic waste under Article 11 (1) of the WFD, it is recommended that the European Commission develops guidance that encourages Member States to implement EPR in order to meet their obligations under the WFD in respect of agricultural plastic waste. It is further recommended that, building on the findings of the current study, such guidance considers the relative merits of voluntary versus mandatory approaches, best practice in respect of the establishment and operation of EPR schemes, and the role of supporting measures such as requirements to participate and a ban on open burning of agri-plastics.

E.3.1.1 Inclusion of BDAPs in EPR

BDAPs should be incorporated into agri-plastic EPR schemes. The EPR scheme can be used as a mechanism to collect data on how and where BDAPs are used. It is envisioned that BDAP producers would be exempt from contributing to EPR collection and treatment costs (as these do not apply to BDAPs which are left to biodegrade in the environment), and instead are required only to pay a data management admin fee.

E.3.2 Standards for BDAPs

Where a standard for a BDAP exists (e.g. EN 17033 for mulch films), only certified BDAPs would be exempt from the EPR collection and treatment costs. This would reduce the risk of agri-plastic producers mislabelling their conventional agri-plastics as 'biodegradable' in an attempt to avoid EPR fees. For the integration of BDAPs into EPR schemes to be effective, the EPR scheme in question would need to have full producer participation and strong data collection requirements – most easily achievable under a mandatory approach.

If the current EN 17033 is to be referenced in EPR schemes as evidence of conformance and exemption from EPR disposal costs it should be revised to reflect best practice and uncertainty. Currently the Standard suggest that growers incorporate the material into soil after the growing period. This may not be possible (or typical practice) for some crops (e.g. vineyards) and therefore this practice is not always observed. It is recommended that no exemption is given to any crop type where the grower cannot provide evidence that soil incorporation is taking place.

For mulch films and other BDAPs that remain on the soil surface a new Standard and associated test method will have to be developed in order to provide a framework to allow such products to benefit from EPR exemptions. Furthermore, BDAP products that do not have a verified and accepted Standard associated with them should be considered as 'mismanaged' if left in the environment in the same way as conventional plastics are currently.

E.3.3 Mandatory Minimum Thickness for Conventional Mulch Films

A mandatory minimum thickness / tensile strength for conventional mulch films could minimise the risk of tearing during the removal process (and plastic fragments subsequently accumulating in the environment). Currently, there is very limited quantitative evidence available to link specific mulch film thicknesses to the proportion of plastic remaining in the environment post-removal. The European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) specifies that for black mulch films the minimum thickness should be 20 - 25µm. However, the standard is not mandatory; the proportion of mulch film products that comply with the standard is not known, although it is understood that the thinnest films possible (~10 µm) are marketed as 'cost saving' albeit this may prove to be a false economy in the longer term if this leads to higher rates of accumulation of film in the soil, which may increase the risk that yields are negatively affected.

It is therefore critical that further research is conducted to better understand the relationship between thickness and removal and whether EN 13655 is sufficient to describe this before any mandatory minimum thickness (or strength) is recommended; after which EN 13655 could be the vehicle for this mandatory specification. This, and a number of other areas for further research are recommended in E.3.2.

E.3.4 Further Research

Throughout this study there has been a notable lack of verifiable data from which to draw conclusions. Therefore, the following data gaps and further research requirements are highlighted:

Data Gaps

- Statistical data on the volumes of agri-plastics placed on the market, their uses and their end-of-life fate at Member State level are missing.
- Much of the research and published evidence on biodegradable mulch films is based on the experience from Southern Europe, in particular Italy. Published data for Northern Europe is absent and the accumulation model developed for this study was based upon observations from one US study.
- The migration of plastic residues into other environments (e.g. waterways) from either conventional or biodegradable mulches incorporated into soil has not been studied or quantified to date.
- There is no verifiable data around the typical amount of conventional mulch film that remains on the field after collection. Whilst several figures have been quoted by stakeholders (ranging from 60-100% removal), this is not confirmed with empirical evidence.
- There is no verifiable data (only expert opinion) around the link between mulch film thickness and the typical amount of conventional mulch film that remains on the field after collection.
- There is no research on the magnitude of the disamenity impact associated with agri-plastics left in the environment.

Cross Cutting Recommendations for Further Research

- Build a robust and accurate monitoring data system on plastic for agriculture. Data collection under EPR could provide this data, and coverage will be best if the EPR schemes are mandatory.
- Develop a spatial model of potential flows from agricultural land to waterways that takes into account the location of farms in relationship to waterways, soil erosion and rain events.

Recommendations for Further Research on Conventional Agri-Plastics

- Commission a field-based study focused on determining typical and optimal practice for conventional mulch film removal. Variables such as crop type and material thickness and removal equipment should be considered.

- Determine whether the existing requirements in the European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) are sufficient that, if made mandatory, will lead to greater removal from soil of conventional mulch films.
- Develop further policy options to enforce/encourage good practice once a dataset for both typical and optimal practice for conventional mulch film removal is acquired. These could *inter alia* include:
  - Requirements for particular removal equipment
  - Guidance for best practice
  - Mulch film design requirements e.g. minimum thickness
  - Restriction of conventional mulch films for particular applications (e.g. for crop types where evidence shows that complete removal of conventional mulch films is not possible)
- Assess how effective mechanical mulch film removal techniques (e.g. the RAFU technology trialled in France) are at reducing contamination, and whether any policies supporting the use of this technology should be implemented.

Recommendations for Further Research on Biodegradable Agri-Plastics

- Conduct further studies into the use of biodegradable mulch films that sample soil over several growing seasons in different climates. Any findings from this research may need to be reflected in an update to EN 17033.
- Develop a standard test method for biodegradation and associated limit threshold requirements for specific products that are left *on* the soil (rather than the existing tests for *in* the soil) e.g. for tree protection products.
- Alongside identifying where particular conventional mulch film applications may prevent removal from the soil, these applications may benefit from incentives for the use of biodegradable mulch films.

E.4.0 Résumé – Français

Une stratégie européenne complète en matière de plastiques a créé les bases d'une nouvelle économie circulaire dans laquelle les matières plastiques restent dans la boucle aussi longtemps que possible en encourageant la réutilisation et la réparation, la refabrication, le recyclage et la prévention des déchets plastiques.

Le nouveau plan d'action en faveur de l'économie circulaire ajoute qu'un cadre politique sur l'utilisation des plastiques biodégradables sera élaboré, sur la base d'une évaluation des applications où cette utilisation peut être bénéfique pour l'environnement.

Cette étude cherche d'abord à quantifier les niveaux actuels de consommation, de collecte séparée et de flux par différentes voies de gestion en fin de vie de chaque catégorie d'agro-plastiques dans l'UE. Elle analyse ensuite les causes des problèmes liés à la collecte inadéquate, à la faible réutilisation et au recyclage des plastiques agricoles *conventionnels*, ainsi que les obstacles techniques et non techniques à l'augmentation des taux de recyclage et de réutilisation. Une analyse similaire est également réalisée pour les agro-plastiques biodégradables. Une base de référence du type "business-as-usual" jusqu'en 2040 est établie, suivie par l'identification d'objectifs et de moyens politiques.

Après l'examen de mesures politiques diverses, les options retenues sont évaluées qualitativement et quantitativement, avec des recommandations pour la Commission en termes de mesures à mettre en oeuvre, ainsi que les besoins futurs en matière de recherche. En général, le choix entre l'utilisation de plastiques conventionnels et biodégradables dans l'agriculture dépendra de la situation locale en matière de collecte et des besoins de l'agriculteur.

E.5.0 Résumé Exécutif - Français

Ce rapport a été préparé pour la Direction Générale Environnement de la Commission Européenne par Eunomia Research & Consulting Ltd et ses partenaires, Deloitte et ENT.

L'objectif général de cette étude, conformément aux termes de référence (ToR), est le suivant :

> *To support the Commission's work on potential policy actions regarding agricultural plastics, and regarding the establishment of a framework for biodegradable plastics.*
>
> *(Soutenir le travail de la Commission sur les actions politiques potentielles concernant les plastiques agricoles, et concernant l'établissement d'un cadre pour les plastiques biodégradables.)*

Le mandat précise en outre que :

> *In particular, the objective of the study is to identify and reduce the environmental impacts associated with conventional and biodegradable agricultural plastics. The main focus will be on their end-of-life, in particular their improper collection and their low reuse and recycling on the one hand and their effective biodegradability on the other hand. The study deals with those agricultural macro-plastics that are deliberately placed in the environment to fulfil a function in the agricultural system (including in horticulture and forestry).*

(En particulier, l'objectif de l'étude est d'identifier et de réduire les impacts environnementaux associés aux plastiques agricoles conventionnels et biodégradables. L'accent sera mis sur leur fin de vie, en particulier leur collecte inadéquate et leur faible réutilisation et recyclage d'une part, et leur biodégradabilité réelle d'autre part. L'étude porte sur les macroplastiques agricoles qui sont délibérément placés dans l'environnement pour remplir une fonction dans le système agricole (y compris dans l'horticulture et la sylviculture).)

E.6.0 Approche

Des recherches approfondies ont été menées afin de comprendre l'état actuel de la situation des agroplastiques dans l'UE (y compris des recherches documentaires et un certain nombre d'entretiens semi-structurés avec les parties prenantes). Ensuite, la méthodologie de la boîte à outils pour une meilleure réglementation a été suivie pour identifier les facteurs de problèmes et, à partir de ceux-ci, développer des objectifs politiques spécifiques pour améliorer la gestion des plastiques agricoles en fin de vie. Les mesures politiques présélectionnées ont ensuite été modélisées pour comprendre les coûts et les avantages associés.

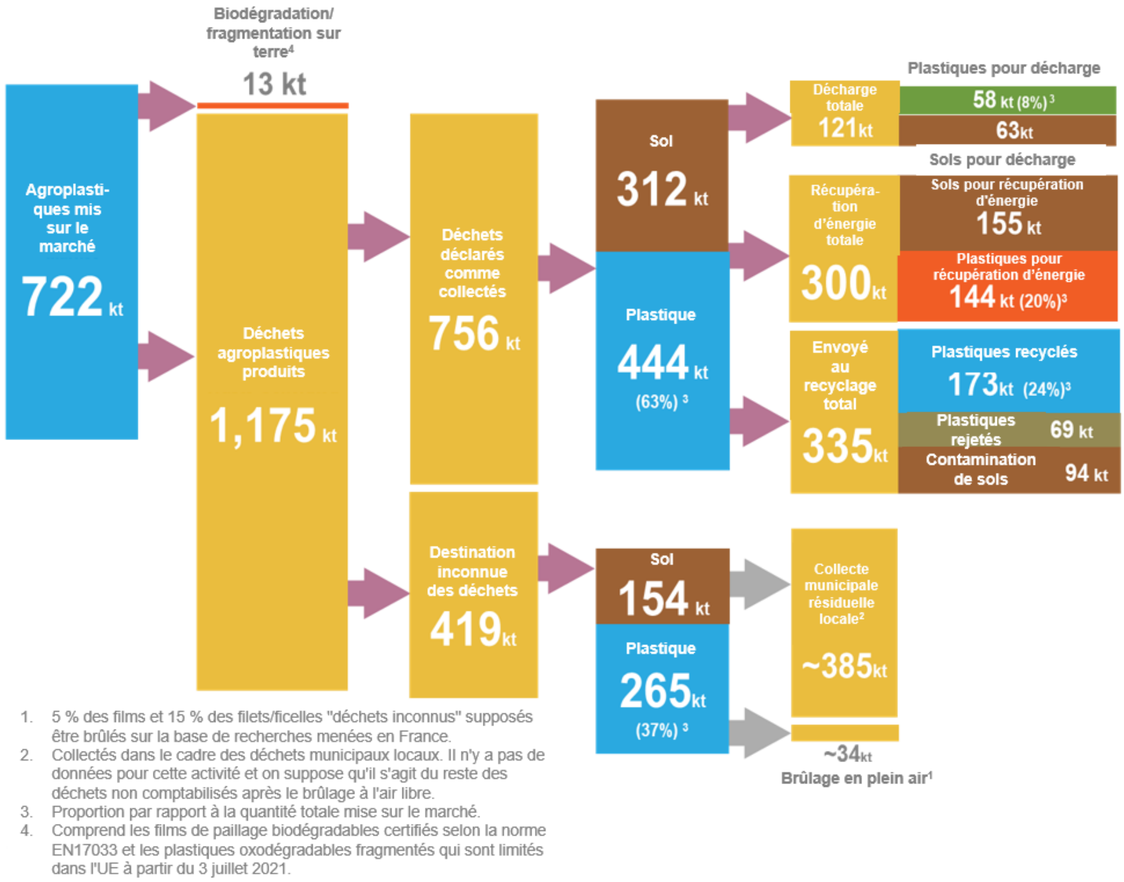
Il **est important de noter que la déclaration statistique de données sur les plastiques agricoles en Europe est encore relativement peu développée.** Cela a nécessité l'utilisation d'estimations et d'hypothèses soigneusement examinées pour certaines données et certains paramètres de modélisation. Des mises en garde concernant les données sont soulignées lorsque nécessaire tout au long du rapport.

E.7.0 Constatations Clés

E.7.1 Quantification de la consommation d'agroplastiques et des pratiques de fin de vie

Environ 63 % des déchets agroplastiques non-emballage générés dans l'UE ont été déclarés comme collectés en 2019 par APE Europe. Le sort des 37% d'agroplastiques restants n'est pas connu - car par définition, cela n'est pas enregistré - mais les agroplastiques peuvent être stockés, brûlés, enterrés ou collectés avec un autre flux de déchets. Des estimations anecdotiques suggèrent qu'environ 5 % des matériaux restants sont brûlés et qu'une grande partie du reste est collectée dans le cadre de programmes locaux de gestion des déchets municipaux, la destination probable étant le traitement résiduel (voir la Figure E- 5). Les pays disposant d'un système de collecte national bien établi, comme l'Irlande, l'Islande, la Norvège, la Suède, la France et l'Espagne, ont atteint un taux de collecte élevé, supérieur à 70 %. Par ailleurs, bien que la plupart des agroplastiques présentent un fort potentiel de recyclage (étant de nature homogène et souvent collectés séparément), on estime que seuls 24 % des déchets agroplastiques non-emballage mis sur le marché chaque année dans l'UE sont actuellement recyclés. Les rendements varient considérablement selon le type d'agroplastique, aucun recyclage n'étant actuellement signalé pour les films de paillage et les filets de balles. À l'inverse, la collecte et le recyclage des films de serre sont relativement bien établis en raison de la haute qualité et de la nature comparativement moins contaminée de ce type d'agroplastique. Les données sous-jacentes montrent que le plastique mis sur le marché ne représente que 60% des déchets générés, le reste étant constitué de terre et d'autres matières organiques. Ce niveau de contamination est propre aux agroplastiques et, comme nous le verrons dans les sections suivantes, il est l'une des principales causes des faibles taux de recyclage signalés. Cette contamination des sols est estimée à environ 467 kt par an dans l'UE, dont 36% (166 kt) proviennent de la collecte des films de paillage, alors qu'ils ne représentent que 12% du marché (en masse). L'enlèvement de la terre des champs contribue à la perte de carbone organique du sol (SOC) - un élément clé de la santé du sol.

Figure E- 5 : Déchets plastiques agricoles de l'UE : débit massique



E.7.2 Aspects de la fin de vie des agroplastiques conventionnels

Les défis liés à la gestion des agroplastiques conventionnels en fin de vie ont été explorés. L'accent a été mis sur deux questions interdépendantes : les obstacles à la collecte séparée des déchets agroplastiques et, une fois collectés, les obstacles à leur recyclage.

E.7.2.1 Obstacles à la collecte

Les principaux obstacles à la collecte séparée des agroplastiques pour le recyclage dans l'UE sont les suivants :

- **Les caractéristiques techniques des films de paillage qui peuvent rendre difficile le retrait complet du film du sol sans qu'il ne se déchire (et que des fragments ne restent**

ensuite dans le sol). Il existe très peu de données sur ce sujet. Toute estimation du pourcentage de films de paillage qui restent dans le sol en Europe est basée sur l'opinion d'experts, plutôt que sur des données collectées, et doit être traitée avec prudence.

- **Des incitations économiques et/ou réglementaires insuffisantes pour la collecte séparée des déchets agroplastiques**. La plupart des produits agroplastiques - à quelques exceptions près - n'ont pas de valeur positive pour les recycleurs, et les gestionnaires de déchets ont donc peu d'incitations économiques à les collecter séparément. En outre, bien que la collecte séparée des déchets plastiques, et donc aussi des agroplastiques, soit exigée par la loi, la mise en œuvre de cette exigence n'est pas suffisante dans toute l'UE.

Et lorsqu'il existe un système de collecte séparée :

- **Une sensibilisation insuffisante des agriculteurs aux systèmes existants.** Par exemple, l'opérateur du système ERDE (le système allemand de collecte des agroplastiques) suggère que la sensibilisation insuffisante des agriculteurs est la raison des taux de collecte actuels, relativement faibles (~40%) ; le système a été lancé en 2013.
- **Des incitations insuffisantes pour que les agriculteurs participent à la collecte séparée des déchets agroplastiques.** Par exemple, les agriculteurs peuvent choisir de brûler leurs déchets agroplastiques sur place ou de les intégrer au flux de déchets ménagers, en particulier pour les déchets agroplastiques de faible volume tels que les filets et les ficelles, qu'il est relativement facile d'inclure discrètement dans le flux de déchets ménagers.

E.7.2.2 Obstacles au recyclage

Les principaux obstacles au recyclage des agroplastiques dans l'UE sont les suivants :

- **Coûts de traitement élevés, principalement en raison des taux de contamination élevés.** Par exemple, les parties prenantes suggèrent que même en appliquant les meilleures pratiques, il faut s'attendre à un taux de contamination de 30 à 40 % pour les films de paillage.
- **Faible valeur/marchés finaux limités pour le recyclat.** La qualité des granulés produits à partir d'agroplastiques est en général relativement médiocre (les films de serre constituent la principale exception à cette règle).

E.7.2.3 Impacts environnementaux de la collecte incorrecte

La collecte inadéquate des agroplastiques est susceptible d'avoir des effets négatifs sur l'environnement et il y a plus de chances que les résidus de plastique pénètrent et restent dans le sol s'ils ne sont pas collectés ; bien que le sort exact de ces résidus reste à déterminer, il est également possible que ceux-ci soient transportés dans d'autres environnements.

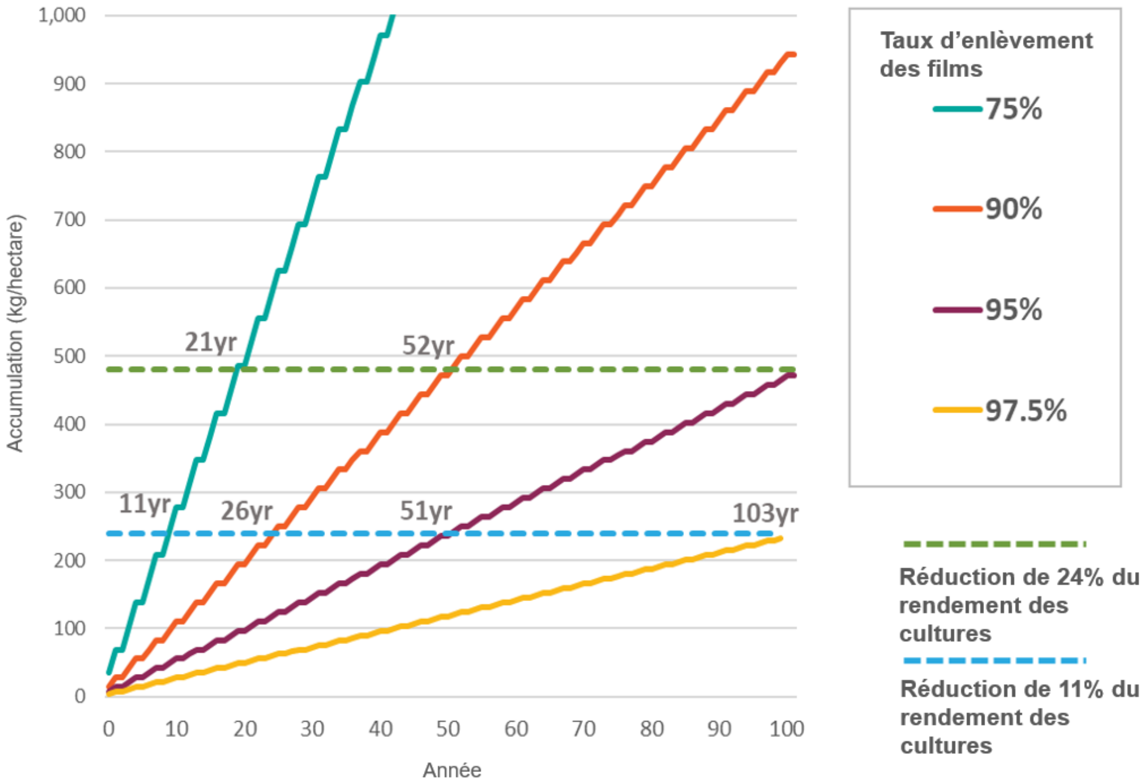
Bien que les recherches spécifiques sur les impacts environnementaux des résidus d'agroplastiques dans le sol ne soient ni expansives ni concluantes, les observations suivantes peuvent être faites :

- La base de preuves scientifiques existante repose sur des exemples en dehors de l'UE, mais les résultats indiquent que si les concentrations atteignent un certain seuil, des effets négatifs sur la fertilité des sols et le rendement des cultures sont probables.
- Les modélisations réalisées dans le cadre de cette étude et portant sur des scénarios probables d'utilisation de films de paillage conventionnels ont montré que ces seuils pourraient être atteints dans un délai de 11 à 51 ans si 5 à 25 % du film n'est pas retiré

du sol après utilisation (voir Figure E- 6). Pour replacer ces chiffres dans leur contexte, **si la moyenne des 5 à 25 % de film de paillage restant est calculée pour l'ensemble de l'UE, l'utilisation annuelle de 83 000 tonnes de film de paillage se traduirait par 4 750 à 20 750 tonnes de plastique conventionnel restant sur les terres agricoles chaque année.**

- La proportion de films de paillage plastique conventionnels qui sont généralement laissés sur place n'est pas connue (des chiffres de l'ordre de 5 à 25 % sont souvent cités, mais la racine de ceux-ci n'a aucun lien direct avec une étude scientifique publiée). Il n'y a pas de lien démontrable entre la pratique courante et le fait qu'une proportion particulière soit laissée sur le terrain. On ne sait pas non plus ce qu'il est possible d'obtenir si les meilleures pratiques sont employées et dans quelle mesure les améliorations technologiques des machines d'enlèvement sur le terrain pourraient y parvenir. Des preuves anecdotiques suggèrent que des films plus épais produiront moins de résidus, mais une étude plus approfondie est nécessaire pour déterminer l'épaisseur exacte (et donc la spécification de résistance) qui serait requise.
- Les faibles taux de collecte augmentent également la probabilité que les agroplastiques soient brûlés à l'air libre. Cette pratique est associée à la libération de sous-produits qui peuvent contribuer de manière significative au réchauffement de la planète, ainsi qu'à des impacts négatifs sur la santé humaine.

Figure E- 6 : Modèle d'accumulation du film de paillis plastique conventionnel



Source : Calculs modélisés par Eunomia

E.7.3 Aspects de la fin de vie des agroplastiques biodégradables

Les plastiques biodégradables sont ceux qui peuvent être décomposés par l'action d'organismes vivants, par exemple des microbes, en eau, dioxyde de carbone et biomasse. Les plastiques biodégradables sont généralement produits à partir de matières premières renouvelables, de micro-organismes, de produits pétrochimiques ou d'une combinaison des trois. Ce rapport se concentre principalement sur les films de paillage biodégradables (FPB) car ce sont les seuls agroplastiques biodégradables qui ont fait l'objet d'études approfondies sur le terrain et qui disposent d'une norme de produit européenne permettant de certifier leur performance (EN 17033). Bien que la base de preuves se concentre sur ces produits, les aspects importants peuvent être transférés pour comprendre les implications d'une utilisation plus répandue dans d'autres types de produits.

E.7.3.1 Conclusions sur le risque environnemental

L'évaluation des impacts environnementaux possibles des FPB est essentielle pour évaluer leur potentiel en tant que substitut des plastiques conventionnels dans l'agriculture. L'examen des preuves a montré que :

- *Pendant l'utilisation*, les effets des FPB sur la santé du sol sont comparables à ceux des paillis conventionnels, bien qu'il y ait un processus d'apprentissage pour le producteur lorsqu'il passe des paillis conventionnels aux FPB pour atteindre une performance optimale. Ceci n'est pas considéré comme un obstacle si une formation et un soutien appropriés sont fournis par le fournisseur du film (ce qui est généralement le cas).
- Étant donné que la biodégradation complète des FPB après leur enfouissement dans le sol peut prendre plus d'un an, la matière peut commencer à s'accumuler dans le sol dans les endroits où la température moyenne du sol est <15°C, mais cette accumulation se stabilise à un faible niveau ;
- Une fois que l'application de FPB cesse ou si une année de jachère est incluse, la présence de FPB dans le sol est susceptible de diminuer rapidement (en 1 à 2 ans) jusqu'à zéro dans les climats tempérés (température du sol >10°C), contrairement au plastique conventionnel qui restera à la même concentration.
- Lorsque l'on utilise l'analyse du cycle de vie (ACV) comme outil de comparaison de l'impact environnemental, les données actuelles suggèrent que les films de paillage conventionnels ont un impact environnemental inférieur à celui des FPB dans la plupart des catégories d'impact. L'incorporation de matériaux recyclés dans les films conventionnels augmente le nombre de catégories d'impact pour lesquelles les FPB sont plus performants. Cependant, il n'est pas encore possible de quantifier de manière comparative l'occurrence et les impacts négatifs associés aux résidus de films de paillage conventionnels restant sur le terrain.
- Les films de paillage biodégradables sont susceptibles de réduire l'apparition et la persistance des plastiques dans l'environnement ouvert, mais il s'agit d'un compromis qu'il n'est pas possible d'appréhender à l'aide des méthodologies d'ACV classiques à l'heure actuelle, et les voies de biodégradation des plastiques biodégradables dans le sol ne sont pas encore complètement comprises.
- La mesure dans laquelle les films de paillage conventionnels ou les films FPB peuvent s'infiltrer dans les cours d'eau ou d'autres habitats n'a fait l'objet d'aucune étude spécifique. Si la lixiviation ou le transport par le vent a lieu pour les fragments de films conventionnels, les preuves existantes suggèrent qu'il y aurait plusieurs impacts négatifs

sur les écosystèmes (mais pas encore quantifiables). Pour les FPB, les impacts sont susceptibles d'être comparativement moindres, mais comme les tests de biodégradation aquatique ne sont généralement pas réalisés sur ces matériaux, il n'y a aucune garantie que l'impact soit nul.

Le Tableau E- 1 résume les principaux compromis entre les films de paillage conventionnels et biodégrables. Il surligne les nombreuses inconnues qui empêchent de tirer des conclusions définitives à l'heure actuelle. Alors que les films de paillage conventionnels, une fois recyclés, sont censés avoir un impact environnemental général sur le cycle de vie inférieur à celui des FPB, le recyclage n'a généralement pas lieu, principalement en raison des niveaux élevés de contamination. Bien qu'il soit possible d'encourager le recyclage des matériaux collectés, des recherches supplémentaires sont nécessaires pour établir s'il est possible d'éliminer systématiquement toute trace de film conventionnel sur le terrain après utilisation. Si cela n'est pas possible, il existe alors un compromis clé entre la pollution plastique dans l'environnement et les émissions de gaz à effet de serre (ainsi que la plupart des autres catégories d'impact environnemental). Si les changements technologiques améliorent l'enlèvement et fournissent des matériaux plus propres dans le système de recyclage, les arguments en faveur de la poursuite de l'utilisation des films de paillage conventionnels seront plus forts. Les progrès dans la production de matières premières biosourcées qui réduisent les impacts environnementaux des matières premières peuvent également influer sur la question de savoir si cette pratique est préférable à l'avenir. **Compte tenu de ce manque de certitude à l'heure actuelle, il est important d'avoir les deux options, le choix de l'une ou l'autre dépendant de la situation locale en matière de collecte et des besoins de l'agriculteur.**

Tableau E- 1 : Résumé des compromis environnementaux des matériaux de film de paillis

Vert = scénarios environnementaux les plus favorables ; **jaune** = scénarios mixtes ou incertains ; **Rouge** = scénarios environnementaux les moins favorables

<table>
<tr><th>Compromis >>
Matériau du paillis[5]</th><th>Matères premières et production</th><th>Décharge</th><th>Incinération</th><th>Laissé dans le sol</th><th>Recyclage</th></tr>
<tr><td>Biodégradable à base biologique</td><td rowspan="2">Impact généralement plus élevé que celui des produits conventionnelsl[1]</td><td rowspan="2">s/o</td><td rowspan="2">s/o</td><td>Libère du CO_2 biogénique ; ~1/3 est converti en biomasse[1]</td><td rowspan="2">N’a pas lieu – perte de valeur matérielle</td></tr>
<tr><td>Biodégradable d’origine fossile</td><td>Libère du CO_2 fossile ; ~1/3 est converti en biomasse[1]</td></tr>
<tr><td>Biomasse Conventionnelle</td><td rowspan="2">Impact généralement plus faible que celui des produits biodégradables</td><td rowspan="2">Inerte, mais possibilité de méthane à partir de résidus organiques</td><td>Libère du CO_2 biogénique</td><td rowspan="2">Persiste[4]</td><td rowspan="2">Le matériau est recyclable[3]</td></tr>
<tr><td>Fossiles Conventionnels</td><td>Libère du CO_2 fossile</td></tr>
</table>

1. Il convient de noter que cela peut changer à mesure que les chaînes d'approvisionnement et les processus de fabrication se développent au fil du temps.
2. On ne sait pas exactement quelles proportions sont converties en CO^2 ou en biomasse. Un chiffre indicatif d'un tiers de conversion en biomasse similaire à celui des plastiques compostables est fourni.
3. Le recyclage des films de paillage dans l'UE n'est généralement pas entrepris - des améliorations futures des taux de collecte et des options politiques qui encouragent le recyclage sont nécessaires.
4. On ne sait pas encore exactement quelle quantité de plastique résiduel subsiste généralement sur le terrain (en raison d'un retrait incorrect ou d'un déchirement des films plus fins).
5. Les matériaux peuvent également être une combinaison de matériaux fossiles et biosourcés. Cela signifie que le même produit peut libérer du CO2 fossile et biogénique en fonction des circonstances.

E.7.3.2 Proposition de critères pour l'utilisation d’agroplastiques biodégradables

Il est clair que les FPB offrent au cultivateur un choix supplémentaire dont les avantages sont incontestables. Les résultats de cette étude ne donnent pas de raison d’établir une loi pour empêcher leur utilisation. Cependant, de nouveaux matériaux sont en développement et de nouvelles applications sont suggérées pour les FPB, de sorte qu'il est nécessaire d'établir un ensemble de principes qui peuvent guider l'utilisation de ces produits vers des applications où un avantage réel peut être obtenu et prévenir les abus et les fausses déclarations.

Le Tableau E- 2 résume les critères proposés qui devraient idéalement être remplis afin de réduire les risques environnementaux (en reconnaissant que l'accent est mis sur le risque comparatif) tout en respectant la hiérarchie des déchets et en mettant l'accent sur les principes de l'économie circulaire.

Il existe deux niveaux de critères : primaire et secondaire. Le niveau primaire est constitué de critères qui représentent des constantes peu susceptibles de changer avec le temps et qui doivent être remplis avant que les critères secondaires ne soient abordés. Les critères secondaires sont des critères fondés sur des preuves qui peuvent être étudiés pour les produits/applications qui répondent aux critères primaires. L'objectif est de préserver les ressources qui pourraient être consacrées au développement de produits, aux essais de biodégradation et à l'élaboration de normes pour des applications inadaptées.

Tableau E- 2 : Critères pour les applications de plastiques biodégradables en agriculture

Niveau primaire
L'utilisation de plastique conventionnel a des répercussions négatives sur l'environnement en raison de l'accumulation de terre et des fuites dans l'environnement.
Le produit ne peut pas être enlevé, collecté et éliminé de manière responsable, sans laisser de résidus à la fin de sa vie.
Niveau secondaire
Il est possible d'obtenir des spécifications et des performances de produit similaires ou améliorées par rapport à l'alternative conventionnelle pendant l'utilisation.
Des essais in situ ont été réalisés pour observer le temps de biodégradation prévu dans un climat particulier.
Une méthode d'essai standard et un seuil de biodégradation sont disponibles (par exemple, EN 17566 et EN 17033)*.
*La norme EN 17566 est une méthode d'essai générique de biodégradation dans le sol. La norme EN17033 spécifie le délai et le seuil de biodégradation que ce test doit respecter pour les films de paillage. Les deux sont requis pour un environnement et un type de produit particuliers, mais il n'existe pas actuellement de tests pour tous les environnements.

Le Tableau E- 3 reprend ces critères et les applique aux applications courantes des plastiques agricoles identifiées dans ce rapport ainsi qu'à certaines applications spéciales ou nouvelles. Les résultats montrent que seules les pellicules de paillage sont considérées comme une application

appropriée pour les matériaux biodégradables à l'heure actuelle, ce qui est conforme aux conclusions des recherches effectuées pour ce rapport. La base de preuves est solide pour cette application et c'est la seule qui peut être vérifiée par l'utilisation d'une norme. À l'autre extrémité de l'échelle, les emballages d'ensilage et les films de serre ne répondent pas au critère principal de l'impossibilité de collecte (car ils peuvent être collectés). Bien que des produits tels que les films de serre ne soient pas promus par les producteurs de plastiques biodégradables, cette étude fournit un cadre qui justifie le maintien de cette position.
En l'absence d'un moyen de tester et de vérifier la biodégradation en milieu ouvert (et compte tenu de la difficulté de le faire), l'accent doit être mis sur la mise en oeuvre efficace de programmes (par exemple, la Responsabilité Elargie des Producteurs) qui incitent les exploitations agricoles à collecter et à gérer tous les déchets plastiques de manière appropriée.

Pour les produits qui peuvent souvent être laissés dans l'environnement, comme la protection des arbres, il y a des arguments en faveur de l'utilisation de matériaux biodégradables pour réduire l'impact - même si la biodégradation complète n'est pas toujours atteinte en raison des conditions particulières, elle peut être une meilleure alternative au plastique conventionnel qui reste pour toujours. Cependant, l'absence de normalisation et de certification pour les produits autres que les FPB rend impossible la différenciation entre les produits fabriqués à partir de matériaux dont la biodégradation est prouvée et ceux qui ne fonctionnent pas comme prévu. Il est clair que la normalisation est essentielle pour créer des conditions de concurrence équitables et empêcher les fausses déclarations.

Tableau E- 3 : Critères d'application pour les applications de plastique BD dans l'agriculture

✓= remplit le critère, ✗ = ne remplit pas le critère, ✓✗ = la base de données n'est pas claire ou est en cours d'élaboration

Critères	Films de paillage - culture à cycle court	Film de paillage pour la production de riz	Ruban de goutte à goutte pour	L'irrigation Protection des arbres	Ficelles et filets	Enveloppes d'ensilage	Greenhouse Films
Critères primaires							
L'utilisation de plastique conventionnel a des répercussions négatives sur l'environnement en raison de l'accumulation de terre et des fuites dans l'environnement.	✓	s/o	✓✗	✓	✓	✓	✓

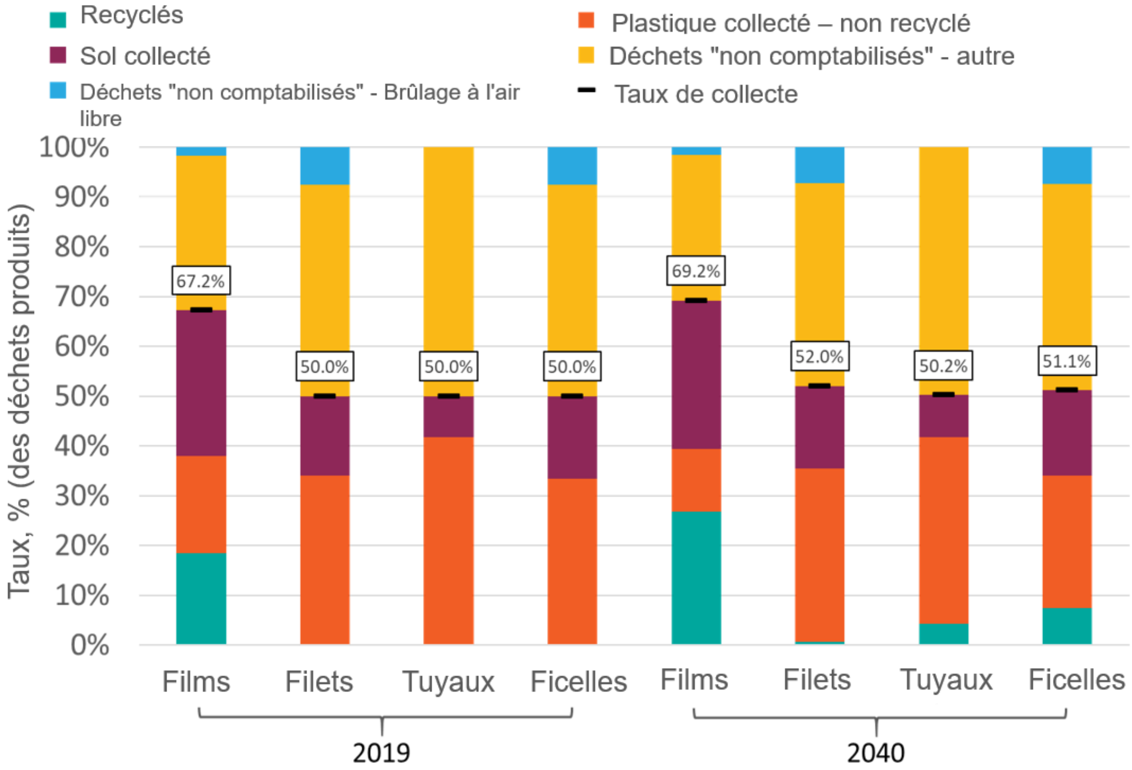
Le produit ne peut pas être enlevé, collecté et éliminé de manière responsable, sans laisser de résidus à la fin de sa vie.	✓	✓	✓✗	✓✗	✓✗	✗	✗
Critères secondaires							
Il est possible d'obtenir des spécifications et des performances similaires ou améliorées du produit pendant son utilisation.	✓	n/a	✗	✓	✓✗	✗	✗
Des essais ont été réalisés sur place pour observer le temps de biodégradation prévu dans un climat particulier.	✓	✓✗	✗	✗	✗	✗	✗
Une méthode d'essai standard et un seuil de biodégradation sont disponibles.	✓	✓✗	✗	✗	✗	✗	✗

E.7.4 Données de base sur la consommation, la production et la gestion des déchets agroplastiques

Une base de référence de la consommation d'agroplastiques, de la production de déchets et des voies de gestion des déchets dans l'UE28 a été modélisée et est présentée dans la section 5.0. On prévoit qu'en l'absence d'autres interventions, la croissance de la collecte et du recyclage des plastiques agricoles conventionnels sera limitée (voir la Figure E- 7). Il est donc recommandé que la Commission européenne prenne des mesures pour améliorer la gestion de la fin de vie des plastiques agricoles conventionnels.

Les destinations finales des déchets produits en 2019 (dernière année des données historiques) et en 2040 (dernière année des projections) sont présentées dans la Figure E- 7. Les taux de collecte sont représentés par une barre noire (et les déchets restants - en jaune - sont "non comptabilisés"). Parmi ces déchets collectés, la fraction violette est constituée de terre (non recyclée). Avant le recyclage final, les pertes supplémentaires de déchets plastiques sont indiquées en orange. Les déchets finaux recyclés sont indiqués en vert. Veuillez noter qu'il s'agit d'un taux de recyclage basé sur les déchets générés (y compris la terre), tandis que les taux de recyclage cités dans ce rapport sont basés sur le plastique recyclé en tant que % du plastique mis sur le marché (c'est-à-dire sans inclure la terre dans les déchets collectés).

Figure E- 7 : Destinations finales des déchets agroplastiques dans l'UE28, en milliers de tonnes (2019, 2040)



E.7.5 Options politiques

Sur la base des obstacles à la collecte et au recyclage des agroplastiques conventionnels identifiés, et de l'évaluation du risque environnemental des plastiques agricoles biodégradables en fin de vie, un certain nombre d'options stratégiques ont été présélectionnées et évaluées (voir section 6.0). Les principales conclusions relatives à la responsabilité élargie des producteurs (REP) et aux mesures de soutien sont les suivantes :

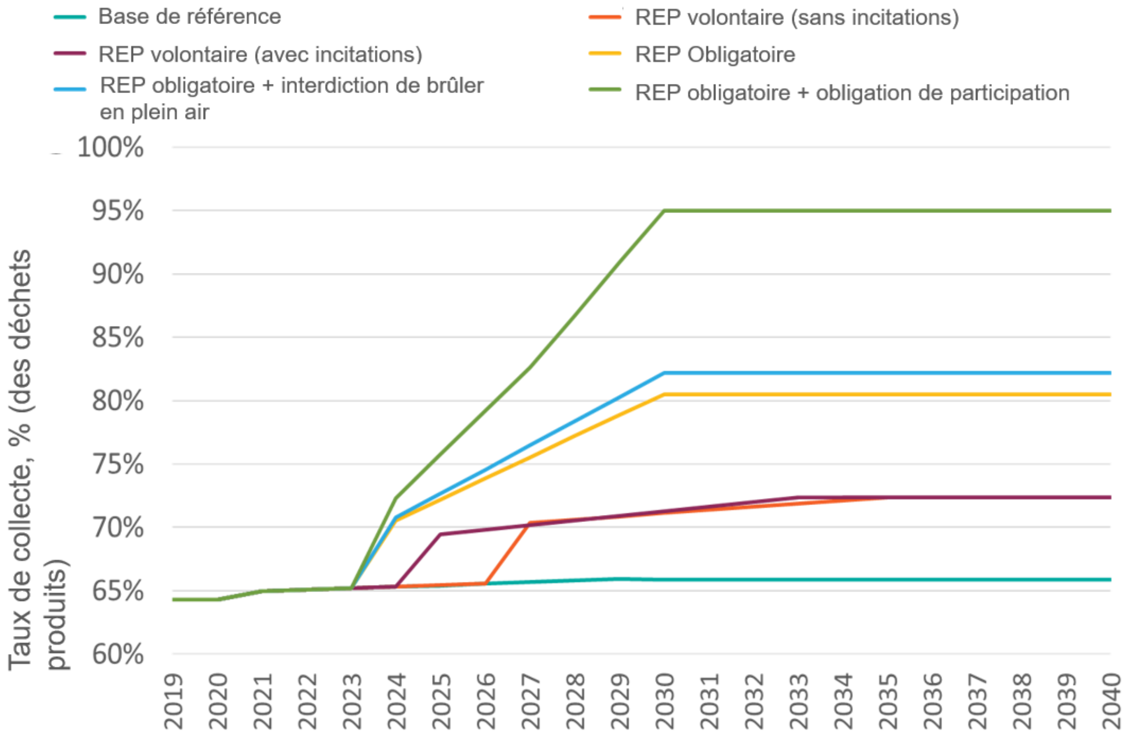
- La mise en oeuvre de la REP pour les agroplastiques est susceptible d'entraîner des améliorations importantes du taux de collecte et de recyclage des agroplastiques dans toute l'UE. En tant que mesure politique, elle est proportionnée et ciblée. Elle permettra également aux États membres de satisfaire à l'exigence de collecte séparée des déchets plastiques, telle qu'elle est définie dans la directive-cadre sur les déchets (DCD), et pour laquelle l'échéance de 2015 est déjà dépassée.
- Trois options sont envisagées pour la mise en oeuvre de la REP : obligatoire ; volontaire (avec incitations) et volontaire (sans incitations). La REP obligatoire est probablement la plus efficace. Il existe des exemples de systèmes de REP volontaires réussis pour les agroplastiques (par exemple, ADIVALOR en France), mais on prévoit que les approches volontaires pourraient avoir du mal à atteindre les taux de collecte les plus élevés.
- Le coût de la gestion des déchets augmente par rapport au scénario de référence pour toutes les options de REP en raison d'une réduction du volume des déchets "non

comptabilisés" (c'est-à-dire les déchets qui ne sont pas déclarés comme ayant été collectés dans le cadre d'un programme de collecte d'agroplastiques). Dans le cadre de la REP, une plus grande partie de ces déchets auparavant "non comptabilisés" est collectée et entraîne donc des coûts de gestion des déchets.

- La REP peut être combinée à d'autres mesures afin d'accroître son efficacité (par exemple, l'interdiction de l'incinération à l'air libre des agroplastiques ou l'obligation pour les agriculteurs de participer à un système de collecte séparée).

La Figure E- 8 montre les taux de collecte modélisés jusqu'en 2040 dans le cadre d'un scénario de base de maintien du système actuel, d'une REP volontaire (avec ou sans incitation) et d'une REP obligatoire. Des taux de collecte plus élevés sont modélisés lorsque la REP obligatoire est associée à des mesures de soutien - interdiction de brûler à l'air libre les déchets agroplastiques et obligation pour les agriculteurs de participer à des programmes de collecte des agroplastiques.

Figure E- 8 : Taux de collecte modélisés (2019 à 2040), %



E.8.0 Recommandations

E.8.1 REP

Compte tenu de l'exigence existante de collecte séparée des déchets plastiques en vertu de l'article 11 (1) de la DCE, il est recommandé que la Commission européenne élabore des orientations qui encouragent les États membres à mettre en oeuvre la REP afin de remplir leurs obligations en vertu de la DCE en ce qui concerne les déchets plastiques agricoles. Il est également recommandé que, sur la base des résultats de la présente étude, ces orientations prennent en compte les mérites relatifs des approches volontaires et obligatoires, les meilleures pratiques en matière de mise en place et de fonctionnement des systèmes de REP, ainsi que le rôle des mesures de soutien telles que l'obligation de participer et l'interdiction du brûlage à l'air libre des agroplastiques.

E.8.1.1 Inclusion des plastiques agricoles biodégradables dans la REP

Les plastiques agricoles biodégradables devraient être intégrés dans les programmes de REP sur les agroplastiques. Le système de REP peut être utilisé comme un mécanisme de collecte de données sur la manière et le lieu d'utilisation des plastiques agricoles biodégradables. Il est envisagé que les producteurs soient dispensés de contribuer aux coûts de collecte et de traitement de la REP (puisque ceux-ci ne s'appliquent pas aux plastiques agricoles biodégradables qui sont laissés à la biodégradation dans l'environnement), et qu'ils soient uniquement tenus de payer des frais administratifs de gestion des données.

E.8.2 Normes pour les plastiques agricoles biodégradables

Lorsqu'il existe une norme pour les plastiques agricoles biodégradables (par exemple, la norme EN 17033 pour les films de paillage), seuls les certifiés seraient exemptés des coûts de collecte et de traitement de la REP. Cela réduirait le risque que les producteurs d'agroplastiques étiquettent à tort leurs agroplastiques conventionnels comme étant " biodégradables " dans le but d'éviter les frais de REP. Pour que l'intégration des plastiques agricoles biodégradables dans les systèmes de REP soit efficace, le système de REP en question devrait prévoir une participation totale des producteurs et des exigences strictes en matière de collecte de données - ce qui est plus facile à réaliser dans le cadre d'une approche obligatoire.

Si la norme EN 17033 actuelle doit être référencée dans les programmes de REP comme preuve de conformité et d'exemption des coûts d'élimination de la REP, elle doit être révisée pour refléter les meilleures pratiques et les incertitudes. Actuellement, la norme suggère aux producteurs d'incorporer le matériau dans le sol après la période de croissance. Cela peut ne pas être possible (ou typique) pour certaines cultures (par exemple les vignobles) et cette pratique n'est donc pas toujours observée. Il est recommandé de ne pas accorder d'exemption à un type de culture lorsque le producteur ne peut pas fournir la preuve que l'incorporation au sol a lieu.

Pour les films de paillage et autres plastiques agricoles biodégradables qui restent à la surface du sol, une nouvelle norme et une méthode d'essai associée devront être développées afin de fournir un cadre permettant à ces produits de bénéficier d'exemptions de REP. En outre, les produits plastiques agricoles biodégradables qui ne sont pas associés à une norme vérifiée et acceptée devraient être considérés comme " mal gérés " s'ils sont laissés dans l'environnement de la même manière que les plastiques conventionnels.

E.8.3 Épaisseur minimale obligatoire pour les films de paillage conventionnels

Une épaisseur/résistance à la traction minimale obligatoire pour les films de paillage conventionnels pourrait minimiser le risque de déchirure pendant le processus d'enlèvement (et l'accumulation ultérieure de fragments de plastique dans l'environnement). Actuellement, il existe très peu de preuves quantitatives permettant d'établir un lien entre les épaisseurs spécifiques des films de paillage et la proportion de plastique restant dans l'environnement après leur enlèvement. La norme européenne pour les " films de paillage thermoplastiques récupérables après usage, pour une utilisation en agriculture et en horticulture " (EN 13655) spécifie que pour les films de paillage noirs, l'épaisseur minimale doit être de 20 - 25µm. Cependant, la norme n'est pas obligatoire ; la proportion de produits de films de paillage conformes à la norme n'est pas connue, bien qu'il soit entendu que les films les plus fins possibles (~10 µm) sont commercialisés pour " faire des économies " bien que cela puisse s'avérer être une fausse économie à long terme si cela entraîne des taux plus élevés d'accumulation de films dans le sol, ce qui peut augmenter le risque que les rendements soient affectés négativement.

Il est donc essentiel que des recherches supplémentaires soient menées pour mieux comprendre la relation entre l'épaisseur et l'enlèvement et pour savoir si la norme EN 13655 est suffisante pour décrire cette relation avant de recommander une épaisseur (ou une résistance) minimale obligatoire, après quoi la norme EN 13655 pourrait être le véhicule de cette spécification obligatoire. Ce point, ainsi qu'un certain nombre d'autres domaines de recherche supplémentaires, sont recommandés sous E.8.4.

E.8.4 Recherches complémentaires

Tout au long de cette étude, il y a eu un manque notable de données vérifiables permettant de tirer des conclusions. Par conséquent, les lacunes suivantes en matière de données et les besoins de recherches supplémentaires sont soulignés :

Lacunes dans les données

- Les données statistiques sur les volumes d'agroplastiques mis sur le marché, leurs utilisations et leur sort en fin de vie au niveau des États membres font défaut.
- La plupart des recherches et des données publiées sur les films de paillage biodégradables sont basées sur l'expérience de l'Europe du Sud, en particulier l'Italie. Les données publiées pour l'Europe du Nord sont absentes et le modèle d'accumulation développé pour cette étude est basé sur les observations d'une étude américaine.
- La migration des résidus de plastique dans d'autres environnements (par exemple les cours d'eau) à partir de paillis conventionnels ou biodégradables incorporés dans le sol n'a pas été étudiée ou quantifiée à ce jour.
- Il n'existe pas de données vérifiables concernant la quantité typique de film de paillage conventionnel qui reste sur le terrain après la collecte. Bien que plusieurs chiffres aient été cités par les parties prenantes (allant de 60 à 100 % d'enlèvement), ils ne sont pas confirmés par des preuves empiriques.

- Il n'existe pas de données vérifiables (seulement des avis d'experts) concernant le lien entre l'épaisseur du film de paillage et la quantité typique de film de paillage conventionnel qui reste sur le champ après la collecte.
- Il n'y a pas de recherche sur l'ampleur de la nuisance associée aux agroplastiques laissés dans l'environnement.

Recommandations transversales pour la poursuite des recherches

- Mettre en place un système de données de surveillance robuste et précis sur le plastique pour l'agriculture. La collecte de données dans le cadre de la REP pourrait fournir ces données, et la couverture sera meilleure si les systèmes de REP sont obligatoires.
- Élaborer un modèle spatial des flux potentiels des terres agricoles vers les cours d'eau qui tienne compte de l'emplacement des exploitations agricoles par rapport aux cours d'eau, de l'érosion des sols et des événements pluvieux**.**

Recommandations pour la poursuite des recherches sur les agroplastiques conventionnels

- Commander une étude sur le terrain visant à déterminer les pratiques typiques et optimales pour l'enlèvement du film de paillage conventionnel. Des variables telles que le type de culture, l'épaisseur du matériau et l'équipement d'enlèvement doivent être prises en compte.
- Déterminer si les exigences actuelles de la norme européenne relative aux "films de paillage thermoplastiques récupérables après usage, utilisés en agriculture et en horticulture" (EN 13655) sont suffisantes et si elles sont rendues obligatoires, elles conduiront à une plus grande élimination des films de paillage conventionnels du sol.
- Développer d'autres options politiques pour imposer/encourager les bonnes pratiques une fois qu'un ensemble de données sur les pratiques typiques et optimales pour l'enlèvement du film de paillage conventionnel sera acquis. Ces options pourraient *entre autres* inclure :
    - Exigences relatives à l'équipement d'enlèvement particulier
    - Guide des meilleures pratiques
    - Exigences relatives à la conception du film de paillage, par exemple l'épaisseur minimale
    - Restriction de l'utilisation des films de paillage conventionnels pour des applications particulières (par exemple, pour les types de cultures pour lesquelles il est prouvé que l'élimination complète des films de paillage conventionnels n'est pas possible)
- Évaluer l'efficacité des techniques d'enlèvement mécanique des pellicules de paillis (par exemple, la technologie RAFU testée en France) pour réduire la contamination, et déterminer s'il convient de mettre en oeuvre des politiques favorisant l'utilisation de cette technologie.

Recommandations pour la poursuite des recherches sur les agroplastiques biodégradables

- Mener des études supplémentaires sur l'utilisation de films de paillage biodégradables qui échantillonnent le sol sur plusieurs saisons de croissance dans différents climats. Les résultats de ces recherches devront peut-être être pris en compte dans une mise à jour de la norme EN 17033.

- Élaborer une méthode d'essai standard pour la biodégradation et les exigences de seuil limite associées pour des produits spécifiques laissés *sur le* sol (plutôt que les essais existants pour ce qui est *dans* le sol), par exemple pour les produits de protection des arbres.
- Outre l'identification des applications particulières de films de paillage conventionnels susceptibles d'empêcher leur retrait du sol, ces applications peuvent bénéficier d'incitations à l'utilisation de films de paillage biodégradables.

E.9.0 Abstrakt – Deutsch

Eine umfassende EU-Kunststoffstrategie hat den Grundstein für eine neue Kunststoff-Kreislaufwirtschaft gelegt, in der Kunststoffe so lange wie möglich im Kreislauf gehalten werden, indem Wiederverwendung und Reparatur, Wiederaufbereitung, Recycling und Vermeidung von Kunststoffabfällen gefördert werden.

Der neue Aktionsplan für die Kreislaufwirtschaft fügt hinzu, dass ein politischer Rahmen für die Verwendung biologisch abbaubarer Kunststoffe entwickelt werden soll, der auf einer Bewertung der Anwendungen basiert, bei denen eine solche Verwendung für die Umwelt von Vorteil sein kann.

In dieser Studie wird zunächst versucht, das derzeitige Niveau des Verbrauchs, der getrennten Sammlung und der Ströme durch verschiedene Entsorgungswege für jede Kategorie von Agrarkunststoffen in der EU zu quantifizieren. Es wird eine Analyse der Problemfaktoren vorgenommen, die mit der unsachgemäßen Sammlung, der geringen Wiederverwendung und dem Recycling von *konventionellen* Agrarkunststoffen verbunden sind, sowie der technischen und nichttechnischen Hindernisse, die einer höheren Recycling- und Wiederverwendungsrate im Wege stehen. Eine ähnliche Analyse wird auch in Bezug auf biologisch abbaubare Agrarkunststoffe durchgeführt. Es wird eine Business-as-usual-Baseline bis 2040 festgelegt, gefolgt von der Identifizierung von Zielen und politischen Maßnahmen.

Nach einer Evaluierung von politischen Maßnahmen werden die auserwählten Optionen qualitativ und quantitativ bewertet und Empfehlungen für die Kommission hinsichtlich der umzusetzenden Maßnahmen sowie des zukünftigen Forschungsbedarfs gegeben. Im Allgemeinen wird die Wahl zwischen der Verwendung von konventionellen und biologisch abbaubaren Kunststoffen in der Landwirtschaft von der örtlichen Sammelsituation und den Anforderungen der Landwirte/-innen abhängen.

E.10.0 Kurzfassung - Deutsch

Dieser Bericht wurde für die GD Umwelt der Europäischen Kommission von Eunomia Research & Consulting Ltd und seinen Partnern Deloitte und ENT erstellt.

Das übergeordnete Ziel dieser Studie ist gemäß den Terms of Reference (ToR):

> *To support the Commission's work on potential policy actions regarding agricultural plastics, and regarding the establishment of a framework for biodegradable plastics.*
>
> *(Unterstützung der Arbeit der Kommission an potenziellen politischen Maßnahmen in Bezug auf landwirtschaftliche Kunststoffe und in Bezug auf die Schaffung eines Rahmens für biologisch abbaubare Kunststoffe.)*

Die ToR besagt weiterhin, dass:

> *In particular, the objective of the study is to identify and reduce the environmental impacts associated with conventional and biodegradable agricultural plastics. The main focus will be on their end-of-life, in particular their improper collection and their low reuse and recycling on the one hand and their effective biodegradability on the other hand. The study deals with those agricultural macro-plastics that are deliberately placed*

in the environment to fulfil a function in the agricultural system (including in horticulture and forestry).

(Ziel der Studie ist es insbesondere, die mit konventionellen und biologisch abbaubaren landwirtschaftlichen Kunststoffen verbundenen Umweltbelastungen zu identifizieren und zu reduzieren. Das Hauptaugenmerk liegt dabei auf ihrem Lebensende, insbesondere auf ihrer unsachgemäßen Sammlung und ihrer geringen Wiederverwendung und Verwertung einerseits und ihrer effektiven biologischen Abbaubarkeit andererseits. Die Studie befasst sich mit jenen landwirtschaftlichen Makrokunststoffen, die bewusst in die Umwelt eingebracht werden, um eine Funktion im landwirtschaftlichen System (auch im Gartenbau und in der Forstwirtschaft) zu erfüllen.)

E.11.0 Ansatz

Es wurden umfangreiche Recherchen durchgeführt, um den aktuellen Stand der Dinge hinsichtlich Agrarkunststoffe in der EU zu verstehen (einschließlich Schreibtischforschung und einer Reihe von halbstrukturierten Interviews mit Interessenvertreter/-innen). Anschließend wurde die Methodik des Instrumentariums für eine bessere Rechtsetzung angewandt, um Problemfaktoren zu identifizieren und daraus spezifische politische Ziele zur Verbesserung des Managements von Agrarkunststoffen am Ende ihrer Lebensdauer zu entwickeln. Die in die engere Wahl gezogenen politischen Maßnahmen wurden dann modelliert, um die damit verbundenen Kosten und Vorteile zu verstehen.

Es ist wichtig zu beachten, dass die statistische Berichterstattung über landwirtschaftliche Kunststoffdaten in Europa noch relativ unterentwickelt ist. Dies machte die Verwendung sorgfältig überlegter Schätzungen und Annahmen für einige Dateneingaben und Modellierungsparameter erforderlich. Im Bericht wird, wo nötig, auf Annahmen und Vorbehalte hingewiesen.

E.12.0 Wesentliche Ergebnisse

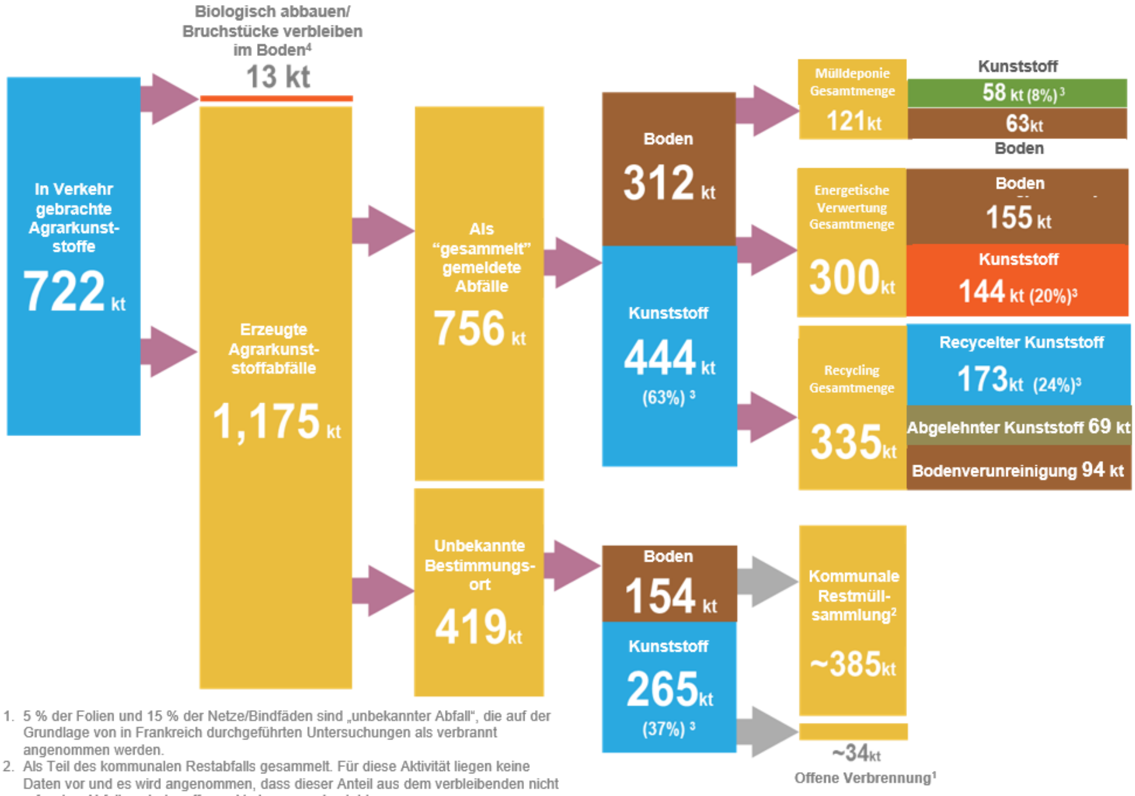
E.12.1 Quantifizierung des Verbrauchs von Agrarkunststoffen und End-of-Life-Praktiken

Etwa 63 % der in der EU anfallenden Nichtverpackungsabfälle aus Agrarkunststoffen wurden 2019 von APE Europe als gesammelt gemeldet. Das Schicksal der verbleibenden 37 % der Agrarkunststoffe ist nicht bekannt - da dies per Definition nicht erfasst wird - aber Agrarkunststoffe können gelagert, verbrannt, vergraben oder mit einem anderen Abfallstrom gesammelt werden. Anekdotische Schätzungen deuten darauf hin, dass etwa 5 % des verbleibenden Materials verbrannt werden und ein Großteil des Rests über lokale kommunale Abfallsysteme gesammelt wird, wobei der wahrscheinliche Bestimmungsort die Reststoffbehandlung ist (siehe Abbildung E- 1). Länder mit einem gut etablierten nationalen Sammelsystem wie Irland, Island, Norwegen, Schweden, Frankreich und Spanien haben eine hohe Sammelquote von mehr als 70 % erreicht. Darüber hinaus werden derzeit schätzungsweise nur 24 % der jährlich in der EU in Verkehr gebrachten Abfälle aus Agrarkunststoffen, und die keine Verpackungen sind, recycelt, obwohl die meisten Agrarkunststoffe ein hohes

Recyclingpotenzial haben (da sie homogen sind und häufig getrennt gesammelt werden). Die Ausbeute ist je nach Art des Agrarkunststoffs sehr unterschiedlich, wobei derzeit keine Berichte über das Recycling von Mulchfolien und Ballennetzen vorliegen. Die Sammlung und Verwertung von Gewächshausfolien ist dagegen relativ gut etabliert, was auf die hohe Qualität und die vergleichsweise geringe Verunreinigung dieser Art von Agrarkunststoffen zurückzuführen ist. Die zugrundeliegenden Daten zeigen, dass in den Verkehr gebrachte Kunststoffe nur 60 % des anfallenden Abfalls ausmacht, der Rest besteht aus Erde und anderen organischen Stoffen.

Dieser Verschmutzungsgrad ist einzigartig für Agrarkunststoffe und ist, wie in den folgenden Abschnitten erörtert, eine der Hauptursachen für die niedrigen gemeldeten Recyclingraten. Die Bodenverunreinigung wird in der EU auf etwa 467 kt pro Jahr geschätzt, wobei 36 % (166 kt) davon aus der Sammlung von Mulchfolien stammen, obwohl diese nur 12 % des Marktes (nach Masse) ausmachen. Die Entfernung der Erde von Feldern trägt zum Verlust von organischem Kohlenstoff im Boden bei, der als Schlüsselkomponente der Bodengesundheit gilt.

Abbildung E- 1 Mengenstrom landwirtschaftlicher Kunststoffabfälle in der EU



1. 5 % der Folien und 15 % der Netze/Bindfäden sind „unbekannter Abfall", die auf der Grundlage von in Frankreich durchgeführten Untersuchungen als verbrannt angenommen werden.
2. Als Teil des kommunalen Restabfalls gesammelt. Für diese Aktivität liegen keine Daten vor und es wird angenommen, dass dieser Anteil aus dem verbleibenden nicht erfassten Abfall nach der offenen Verbrennung besteht.
3. Anteil an der in Verkehr gebrachten Gesamtmenge (722 kt)
4. Umfasst biologisch abbaubare Mulchfolien zertifiziert nach EN 17033 und fragmentierte oxo-abbaubare Kunststoffe, die ab dem 3. Juli 2021 in der EU eingeschränkt sind.

E.12.2 End-of-Life-Aspekte von konventionellen Agrarkunststoffen

Die Herausforderungen im Zusammenhang mit dem Management konventioneller Agrarkunststoffe am Ende ihres Lebenszyklus wurden untersucht. Der Schwerpunkt lag dabei auf zwei miteinander verbundenen Themen: Hindernisse für die getrennte Sammlung von Agrarkunststoffabfällen und - nach der Sammlung - Hindernisse für deren Recycling.

E.12.2.1 Hindernisse für die Sammlung

Die größten Hindernisse für die getrennte Sammlung von Agrarkunststoffen für das Recycling in der gesamten EU sind:

- **Technische Eigenschaften von Mulchfolien, die dazu führen können, dass es schwierig ist, die Folie vollständig vom Boden zu entfernen, ohne dass sie reißt (und Bruchstücke anschließend im Boden verbleiben).** Es gibt nur sehr wenige Daten zu diesem Thema. Jede Schätzung des Prozentsatzes von Mulchfolien, die in Europa im Boden verbleiben, basiert auf Expertenmeinungen und nicht auf gesammelten Daten und sollte daher mit Vorsicht behandelt werden.
- **Unzureichende wirtschaftliche und / oder gesetzliche Anreize für die getrennte Sammlung von Agrarkunststoffabfällen.** Die meisten Agrarkunststoffprodukte - mit wenigen Ausnahmen - haben keinen positiven Wert für die Verwerter und daher gibt es wenig wirtschaftlicher Anreiz für die Abfallwirtschaft, sie getrennt zu sammeln. Darüber hinaus ist die getrennte Sammlung von Kunststoffabfällen, und damit auch von Agrarkunststoffen, zwar gesetzlich vorgeschrieben, die Umsetzung dieser Anforderung ist jedoch EU-weit nicht ausreichend.

Und wenn ein separates Sammelsystem existiert:

- **Unzureichendes Bewusstsein der Beschäftigten in der Landwirtschaft für bestehende Systeme.** Der Systembetreiber von ERDE (dem deutschen System zur Sammlung von Agrarkunststoffen) gibt beispielsweise an, dass ein unzureichendes Bewusstsein der landwirtschaftlich Beschäftigten der Grund für die derzeitige, relativ niedrige Sammelquote (~40 %) ist; das System wurde 2013 eingeführt.
- **Unzureichende Anreize für Beschäftigte in der Landwirtschaft, sich an der getrennten Sammlung von Agrarkunststoffabfällen zu beteiligen.** Landwirte/-innen können sich beispielsweise dafür entscheiden, ihre Agrarkunststoffabfälle vor Ort zu verbrennen oder in den Restmüllstrom zu leiten, insbesondere bei Agrarkunststoffen mit geringen Volumen wie Netze und Bindfäden, die sich relativ einfach in den Restmüllstrom integrieren lassen.

E.12.2.2 Hindernisse für das Recycling

Die größten Hindernisse für das Recycling von Agrarkunststoffen in der EU sind:

- **Hohe Verarbeitungskosten vor allem aufgrund hoher Kontaminationsraten.** So weisen Interessenvertreter/-innen darauf hin, dass selbst bei Anwendung der besten Praktiken eine Kontaminationsrate von 30 % bis 40 % bei Mulchfolien zu erwarten ist.
- **Geringer Wert / begrenzte Endmärkte für Rezyklat.** Die Qualität des aus Agrarkunststoffen hergestellten Granulats ist im Allgemeinen relativ schlecht (die wichtigste Ausnahme sind Gewächshausfolien).

E.12.2.3 Umweltauswirkungen einer unsachgemäßen Sammlung

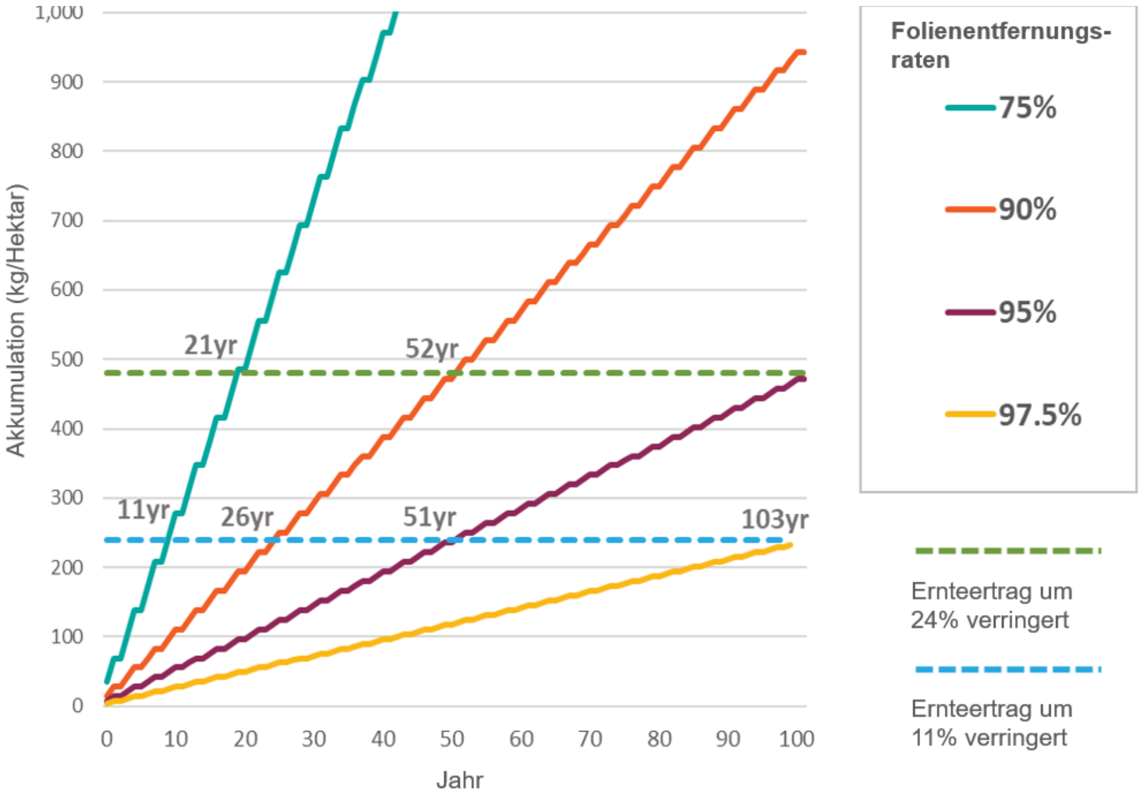
Die unsachgemäße Sammlung von Agrarkunststoffen wird wahrscheinlich zu negativen Umweltauswirkungen führen, und es besteht eine größere Wahrscheinlichkeit, dass Kunststoffreste in den Boden gelangen und dort verbleiben, wenn sie nicht gesammelt werden; obwohl der genaue Verbleib solcher Reste noch erfasst werden muss, ist es auch möglich, dass diese in andere Umgebungen transportiert werden können.

Während spezifische Untersuchungen zu den Umweltauswirkungen von Agrarkunststoffrückständen im Boden weder umfangreich noch schlüssig sind, können folgende Beobachtungen gemacht werden:

- Die vorhandenen wissenschaftlichen Erkenntnisse stützen sich auf Beispiele von außerhalb der EU, aber die Ergebnisse zeigen, dass bei Erreichen einer bestimmten Konzentrationsschwelle negative Auswirkungen auf die Bodenfruchtbarkeit und den Ernteertrag wahrscheinlich sind.
- Eine im Rahmen dieser Studie durchgeführte Modellierung, die wahrscheinliche Szenarien für die Verwendung konventioneller Mulchfolien untersuchte, ergab, dass solche Schwellenwerte innerhalb von 11-51 Jahren erreicht werden könnten, wenn 5-25 % der Folien nach der Verwendung nicht vom Boden entfernt werden (siehe Abbildung E- 2). Um dies in einen Kontext zu setzen: **wenn 5-25% der verbleibenden Mulchfolien im EU-Durchschnitt verwendet werden, würde die jährliche Verwendung von 83.000 Tonnen Mulchfolien dazu führen, dass jedes Jahr 4.750 bis 20.750 Tonnen konventioneller Kunststoff auf landwirtschaftlichen Flächen verbleiben.**
- Der Anteil an konventionellen Kunststoffmulchfolien, der typischerweise übrigbleibt, ist nicht bekannt (häufig werden Zahlen im Bereich von 5-25 % genannt, die jedoch nicht direkt auf eine veröffentlichte wissenschaftliche Studie zurückgeführt werden kann). Es gibt keinen nachweisbaren Zusammenhang zwischen gängiger Praxis und einem bestimmten Anteil, der auf dem Feld verbleibt. Es ist auch unklar, was bei Anwendung der besten Praxis erreichbar ist und inwieweit technologische Verbesserungen bei den Maschinen zur Feldräumung erreicht werden können. Anekdotische Hinweise deuten darauf hin, dass dickere Folien zu weniger Rückständen führen, aber es sind weitere Studien erforderlich, um die genaue Dicke (und damit die Festigkeit) zu bestimmen, die erforderlich wäre.

- Niedrige Sammelraten erhöhen auch die Wahrscheinlichkeit, dass Agrarkunststoffe im Freien verbrannt werden. Diese Praxis ist mit der Freisetzung von Nebenprodukten verbunden, die ein erhebliches Potenzial haben, zur globalen Erwärmung beizutragen, sowie negative Auswirkungen auf die menschliche Gesundheit haben.

Abbildung E- 2 Konventionelles Kunststoffmulchfolien – Akkumulationsmodell



Quelle: Modellrechnungen von Eunomia

E.12.3 End-of-Life-Aspekte von biologisch abbaubaren Agrarkunststoffen

Biologisch abbaubare Kunststoffe sind solche, die durch die Einwirkung von lebenden Organismen, z. B. Mikroben, in Wasser, Kohlendioxid und Biomasse zersetzt werden können. Biologisch abbaubare Kunststoffe werden üblicherweise mit erneuerbaren Rohstoffen, Mikroorganismen, Petrochemikalien oder Kombinationen aus allen drei hergestellt. Der Schwerpunkt dieses Berichts liegt auf biologisch abbaubaren Mulchfolien (BAM), da sie die einzigen biologisch abbaubaren Agrarkunststoffe sind, die umfangreichen Feldstudien unterzogen wurden und für die es eine europäische Produktnorm gibt, die deren Leistung zertifiziert (EN 17033). Während sich die Evidenzbasis auf diese Produkte konzentriert, können die wichtigen Aspekte übertragen werden, um die Auswirkungen einer weiter verbreiteten Verwendung bei anderen Produkttypen zu verstehen.

E.12.3.1 Schlussfolgerungen zum Umweltrisiko

Die Beurteilung der möglichen Umweltauswirkungen von BAM ist entscheidend für die Bewertung ihres Potenzials als Ersatz für konventionelle Kunststoffe in der Landwirtschaft. Die Überprüfung der Beweise hat gezeigt, dass:

- Während der Anwendung sind die Auswirkungen von BAM auf die Bodengesundheit vergleichbar mit denen von konventionellen Mulchen, obwohl es einen Lernprozess für Landwirte/-innen gibt, wenn sie von konventionellen auf BAM umsteigen, um eine optimale Leistung zu erreichen. Dies wird nicht als Hindernis angesehen, wenn Folienlieferanten/-innen entsprechende Schulungen und Unterstützung anbieten (was in der Regel der Fall ist).
- Da der vollständige biologische Abbau von BAM nach dem Einbringen in den Boden mehr als ein Jahr dauern kann, kann sich das Material an Orten mit einer durchschnittlichen Bodentemperatur von <15 Grad im Boden anreichern, was sich jedoch auf einem niedrigen Niveau stabilisiert;
- Sobald die Ausbringung von BAM eingestellt wird oder wenn ein Brachjahr eingeschlossen ist, wird das Vorhandensein von BAM im Boden in gemäßigten Klimazonen (Bodentemperatur >10 Grad) wahrscheinlich schnell (innerhalb von 1-2 Jahren) auf Null abnehmen; dies steht im Gegensatz zu konventionellem Kunststoff, der in derselben Konzentration verbleibt.
- Bei der Verwendung von Ökobilanzen als Instrument zum Vergleich der Umweltauswirkungen deuten die derzeitigen Erkenntnisse darauf hin, dass konventionelle Mulchfolien im Vergleich zu BAM in den meisten Wirkungskategorien eine geringere Umweltbelastung aufweisen. Durch den Einsatz von Rezyklat in konventionellen Folien erhöht sich die Anzahl der Wirkungskategorien, in denen BAM übertroffen werden. Das Auftreten und die negativen Auswirkungen, die mit auf dem Feld verbleibenden Resten konventioneller Mulchfolien verbunden sind, können jedoch noch nicht vergleichend quantifiziert werden.
- Biologisch abbaubare Mulchfolien reduzieren wahrscheinlich das Vorkommen und die Persistenz von Kunststoffen in der freien Natur, aber dies ist ein Kompromiss, der derzeit nicht durch typische Ökobilanz-Methoden erfasst werden kann, und die Bioabbauwege von biologisch abbaubaren Kunststoffen im Boden müssen noch vollständig verstanden werden.
- Das Ausmaß, in dem konventionelle Mulchfolien oder BAM in Gewässer oder andere Lebensräume ausgewaschen werden können, ist nicht Gegenstand einer spezifischen Studie. Sollte es bei konventionellen Folienfragmenten zu einer Auswaschung oder einem Windtransport kommen, gibt es Hinweise darauf, dass es zu verschiedenen (aber noch nicht quantifizierbaren) negativen Auswirkungen auf das Ökosystem kommen würde. Für BAM sind die Auswirkungen wahrscheinlich vergleichsweise geringer aber, da für diese Materialien in der Regel keine Tests zur biologischen Abbaubarkeit in Gewässern durchgeführt werden, gibt es keine Garantie, dass die Auswirkungen gleich null wären.

Tabelle E- 1 fasst die wichtigsten Kompromisse zwischen konventionellen und BAM zusammen. Sie hebt die erheblichen Unbekannten hervor, die zum jetzigen Zeitpunkt definitive Schlussfolgerungen verhindern. Während man annimmt, dass konventionelle Mulchfolien, sobald sie recycelt werden, eine geringere Gesamtumweltbelastung über den Lebenszyklus haben als BAM, findet das Recycling in der Regel nicht statt, vor allem aufgrund des hohen Verschmutzungsgrades. Obwohl es möglich sein könnte, Anreize für das Recycling von gesammeltem Material zu schaffen, sind weitere Untersuchungen erforderlich, um festzustellen, ob es möglich ist, konsequent alle Spuren von konventionellen Folien nach der Verwendung vom Feld zu entfernen. Wenn dies nicht möglich ist, besteht ein entscheidender Zielkonflikt zwischen der Verschmutzung der Umwelt durch Plastik und den Treibhausgasemissionen (sowie den meisten anderen Kategorien von Umweltauswirkungen). Wenn Änderungen in der Technologie die Entfernung verbessern und saubereres Material in das Recyclingsystem liefern, wird dies ein stärkeres Argument für die weitere Verwendung konventioneller Mulchfolien liefern. Fortschritte bei der Produktion von biobasierten Rohstoffen, die die Umweltauswirkungen der Rohstoffe reduzieren, können ebenfalls Einfluss darauf haben, ob diese Praxis in Zukunft vorzuziehen ist. **In Anbetracht dieses Mangels an Gewissheit ist es wichtig, beide Optionen zur Verfügung zu haben, wobei die Entscheidung, welche verwendet wird, von der örtlichen Sammelsituation und den Anforderungen der Landwirtschaft abhängt.**

Tabelle E- 1 Zusammenfassung der Umweltverträglichkeit von Mulchfolienmaterial

Grün = günstigste Umweltszenarien; **Gelb** = gemischte oder unsichere Szenarien; **Rot** = ungünstigste Umweltszenarien

Kompromiss >> Mulchmaterial[5]	**Rohmaterialien und Produktion**	**Mülldeponie**	**Energetische Verwertung**	**Im Boden verbleibend**	**Recycling**
Biobasiert biologisch abbaubar	Generell höhere Belastung als konventionell[1]	n.z.	n.z.	Setzt **biogenes** CO_2 frei; ~1/3 wird in Biomasse umgewandelt[1]	Findet nicht statt - Materialwert geht verloren
Fossil-basiert biologisch abbaubar				Setzt **fossiles** CO_2 frei; ~1/3 wird in Biomasse umgewandelt[1]	
Biobasiert konventionell	Generell geringere Auswirkungen als biologisch abbaubar	Inert aber Möglichkeit von Methan aus organischen Rückständen	Setzt biogenes CO_2 frei	Verbleibt[4]	Material ist recycelbar[3]
Fossil-basiert konventionell			Setzt fossiles CO_2 frei		

1. Es ist zu beachten, dass sich dies im Laufe der Entwicklung von Lieferketten und Fertigungsprozessen ändern kann.
2. Es ist unklar, welche Anteile genau in CO_2 oder Biomasse umgewandelt werden. Es wird ein Richtwert von 1/3 Umwandlung in Biomasse angegeben, ähnlich wie bei kompostierbaren Kunststoffen.
3. Das Recycling von Mulchfolien wird in der EU in der Regel nicht durchgeführt - zukünftige Verbesserungen der Sammelraten und politische Optionen, die das Recycling fördern, sind erforderlich.
4. Es ist unklar, wie viel Restkunststoff typischerweise im Feld verbleibt (durch unsachgemäße Entfernung oder Reißen der dünneren Folien) zu diesem Zeitpunkt.
5. Folien können auch aus einer Kombination fossil- und biobasierter Materialen bestehen. Das bedeutet, dass je nach Umständen sowohl fossiles als auch biogenes CO2 aus demselben Produkt freigesetzt werden kann.

E.12.3.2 Vorschlag von Kriterien für die Verwendung von biologisch abbaubaren Agrarkunststoffen

Es ist klar, dass BAM den Landwirte/-innen eine zusätzliche Wahlmöglichkeit bieten, deren Vorteile überzeugend sind. Die Ergebnisse dieser Studie geben keinen Anlass, den Einsatz dieser Produkte gesetzlich zu verhindern. Es werden jedoch neue Materialien entwickelt und neue Anwendungen für biologisch abbaubare Agrarkunststoffe (BAAK) vorgeschlagen, so dass ein Bedarf an einer Reihe von Grundsätzen besteht, die den Einsatz dieser Produkte auf Anwendungen lenken können, bei denen ein tatsächlicher Vorteil erzielt werden kann, und die Missbrauch und falsche Behauptungen verhindern.

Tabelle E- 2 fasst die vorgeschlagenen Kriterien zusammen, die idealerweise erfüllt werden sollten, um die Umweltrisiken zu reduzieren (wobei anerkannt wird, dass der Schwerpunkt auf dem Vergleichsrisiko liegt), während gleichzeitig die Abfallhierarchie und die Prinzipien der Kreislaufwirtschaft berücksichtigt werden.

Es gibt zwei Ebenen von Kriterien; primäre und sekundäre. Die primäre Ebene besteht aus Kriterien, die Konstanten darstellen, die sich im Laufe der Zeit wahrscheinlich nicht ändern werden und erfüllt sein sollten, bevor die sekundären Kriterien behandelt werden. Sekundäre Kriterien sind evidenzbasierte Kriterien, die für Produkte/Anwendungen untersucht werden können, die die primären Kriterien erfüllen. Dadurch sollen Ressourcen eingespart werden, die für die Produktentwicklung, die Prüfung der biologischen Abbaubarkeit und die Entwicklung von Normen für ungeeignete Anwendungen aufgewendet werden könnten.

Tabelle E- 2 Kriterien für Anwendungen von biologisch abbaubarem Kunststoff in der Landwirtschaft

Primäre Ebene
Die Verwendung von konventionellem Kunststoff führt zu negativen Umweltauswirkungen im Zusammenhang mit der Anreicherung des Bodens/dem Austritt in die Umwelt
Das Produkt kann nicht praktikabel entfernt, gesammelt und verantwortungsvoll entsorgt werden, so dass am Ende der Lebensdauer keine Rückstände zurückbleiben
Sekundäre Ebene
Ähnliche oder verbesserte Produktspezifikation und Leistung im Vergleich zur konventionellen Alternative während des Gebrauchs kann erreicht werden

Tests vor Ort wurden durchgeführt, um die in einem bestimmten Klima zu erwartende biologische Abbaudauer zu beobachten
Eine genormte Prüfmethode und biologische Abbaugrenze ist verfügbar (z. B. EN 17566 und EN 17033)*
*EN 17566 ist eine generische Testmethode für die biologische Abbaubarkeit im Boden. EN17033 spezifiziert das Zeitlimit und den Schwellenwert für die biologische Abbaubarkeit, die dieser Test für Mulchfolien erfüllen sollte. Beide sind für eine bestimmte Umgebung und einen bestimmten Produkttyp erforderlich, aber es gibt derzeit keine Tests für alle Umgebungen.

Tabelle E- 3 nimmt diese Kriterien und wendet sie auf die in diesem Bericht identifizierten üblichen landwirtschaftlichen Kunststoffanwendungen, sowie auf einige Nischen- und/oder neuartige Anwendungsbeispiele an. Die Ergebnisse zeigen, dass derzeit nur Mulchfolien als geeignete Anwendung für biologisch abbaubare Materialien angesehen werden, was mit den Ergebnissen der Recherche für diesen Bericht übereinstimmt. Die Evidenzbasis ist stark für diese Anwendung und es ist die Einzige, die durch die Verwendung einer Norm verifiziert werden kann. Am anderen Ende der Skala scheitern sowohl Silofolien als auch Gewächshausfolien an dem primären Kriterium, so dass eine Sammlung nicht möglich ist (da diese praktikabel gesammelt werden können). Während Produkte wie Gewächshausfolien von den Herstellern/-innen biologisch abbaubarer Kunststoffe nicht gefördert werden, bietet dies einen Rahmen, der die Beibehaltung dieser Position rechtfertigt.

Ohne eine Möglichkeit, die biologische Abbaubarkeit in der freien Natur zu testen und zu verifizieren (und in Anbetracht der Schwierigkeit, dies zu tun), sollte der Schwerpunkt auf der effektiven Umsetzung von Systemen (z. B. der erweiterten Herstellerverantwortung) liegen, die den Landwirtschaftsbetrieben ein überzeugendes Argument liefern, alle Kunststoffabfälle zu sammeln und angemessen zu behandeln.

Für Produkte, die oft in der Umwelt verbleiben können, wie z. B. Baumschutz, gibt es ein Argument für die Verwendung biologisch abbaubarer Materialien, um die Auswirkungen auf die Umwelt zu verringern - selbst wenn aufgrund der besonderen Bedingungen nicht immer ein vollständiger biologischer Abbau erreicht wird, kann dies eine bessere Alternative sein als herkömmlicher Kunststoff, der für immer bleibt. Die fehlende Standardisierung und Zertifizierung für andere Produkte als BAM macht es jedoch unmöglich, zwischen Produkten aus Materialien mit nachgewiesener biologischer Abbaubarkeit und solchen, die nicht die behauptete Leistung erbringen, zu unterscheiden. Es ist klar, dass eine Standardisierung entscheidend ist, um gleiche Wettbewerbsbedingungen zu schaffen und falsche Behauptungen zu verhindern.

Tabelle E- 3 Anwendungskriterien für biologisch abbaubare Kunststoff-anwendungen in der Landwirtschaft

✓= erfüllt Kriterium, ✗ = verfehlt Kriterium, ✓✗ = Evidenzbasis ist unklar/oder wird entwickelt

Kriterien	Mulchfolien - kurzzyklischer Anbau	Mulchfolie für die Reisproduktion	Tropfband für die Bewässerung	Baumschutz	Bindfäden und Netze	Silofolien	Gewächshaus-folien
Primäre Kriterien							

Die Verwendung von konventionellem Kunststoff führt zu negativen Umweltauswirkungen im Zusammenhang mit der Anreicherung des Bodens/dem Austritt in die Umwelt	✓	n/a	✓✗	✓	✓	✓	✓
Das Produkt kann nicht praktikabel entfernt, gesammelt und verantwortungsvoll entsorgt werden, so dass am Ende der Lebensdauer keine Rückstände zurückbleiben	✓	✓	✓✗	✓✗	✓✗	✗	✗
Sekundäre Kriterien							
Ähnliche oder verbesserte Produktspezifikation und Leistung während des Gebrauchs können erreicht werden	✓	n/a	✗	✓	✓✗	✗	✗
Tests vor Ort wurden durchgeführt, um die in einem bestimmten Klima zu erwartende biologische Abbaudauer zu beobachten	✓	✓✗	✗	✗	✗	✗	✗
Ein Standard-Testverfahren und eine biologische Abbaugrenze sind verfügbar	✓	✓✗	✗	✗	✗	✗	✗

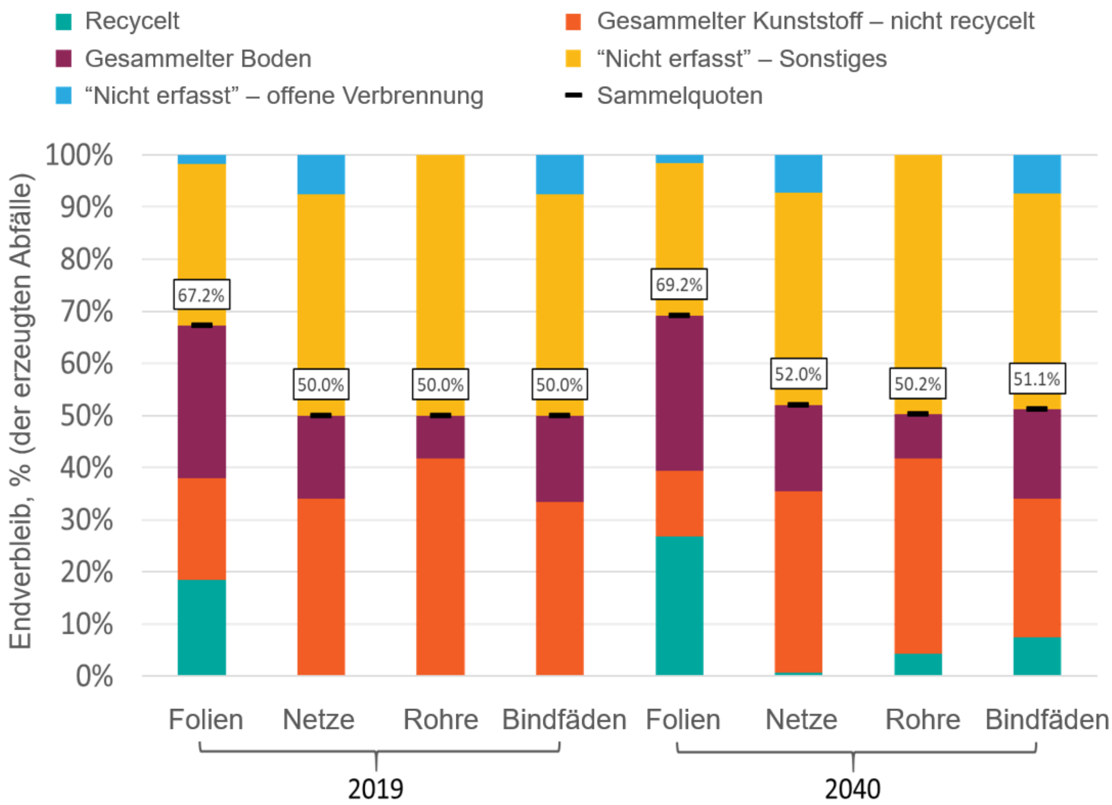
E.12.4 Baseline des Verbrauchs von Agrarkunststoffen, des Abfallaufkommens und des Managements

Eine Baseline des Verbrauchs von Agrarkunststoffen, des Abfallaufkommens und der Abfallentsorgungswege in der EU28 wurde modelliert und ist in Abschnitt 5.0 dargestellt. Es wird davon ausgegangen, dass es ohne weitere Maßnahmen nur ein begrenztes Wachstum bei der Sammlung und dem Recycling von konventionellen Agrarkunststoffen geben wird (siehe Abbildung E- 3). Daher wird empfohlen, dass die Europäische Kommission Maßnahmen zur Verbesserung des End-of-Life-Managements von konventionellen Agrarkunststoffen ergreift.

Die endgültigen Bestimmungsorte des erzeugten Abfalls für 2019 (das letzte Jahr der historischen Daten) und 2040 (das letzte Jahr der Prognosen sind in Abbildung E- 3). Die Sammelquoten sind als schwarzer Balken dargestellt (und der verbleibende Abfall - in gelb - ist "nicht erfasst"). Von diesem gesammelten Abfall ist der violette Anteil Boden (nicht recycelt). Vor dem endgültigen Recycling sind weitere Verluste von Kunststoffabfällen in orange dargestellt. Der endgültig recycelte Abfall ist in grün dargestellt. Bitte beachten Sie, dass es sich hierbei um eine Recyclingquote handelt, die auf dem erzeugten Abfall (einschließlich Boden) basiert, während die in diesem Bericht angegebenen Recyclingquoten auf dem recycelten Kunststoff in %

des auf den Markt gebrachten Kunststoffs basieren (d. h. ohne den Boden im gesammelten Abfall).

Abbildung E- 3 Endverbleib von Agrarkunststoffabfällen in der EU28, tausend Tonnen (2019, 2040)



E.12.5 Politische Optionen

Basierend auf den identifizierten Hindernissen für die Sammlung und das Recycling von konventionellen Agrarkunststoffen und der Bewertung des Umweltrisikos von BAAK am Ende ihrer Lebensdauer wurde eine Reihe von politischen Optionen in die engere Wahl gezogen und bewertet (siehe Abschnitt 6.0). Die wichtigsten Ergebnisse in Bezug auf die erweiterte Herstellerverantwortung (extended producer responsibility, EPR) und unterstützende Maßnahmen sind wie folgt:

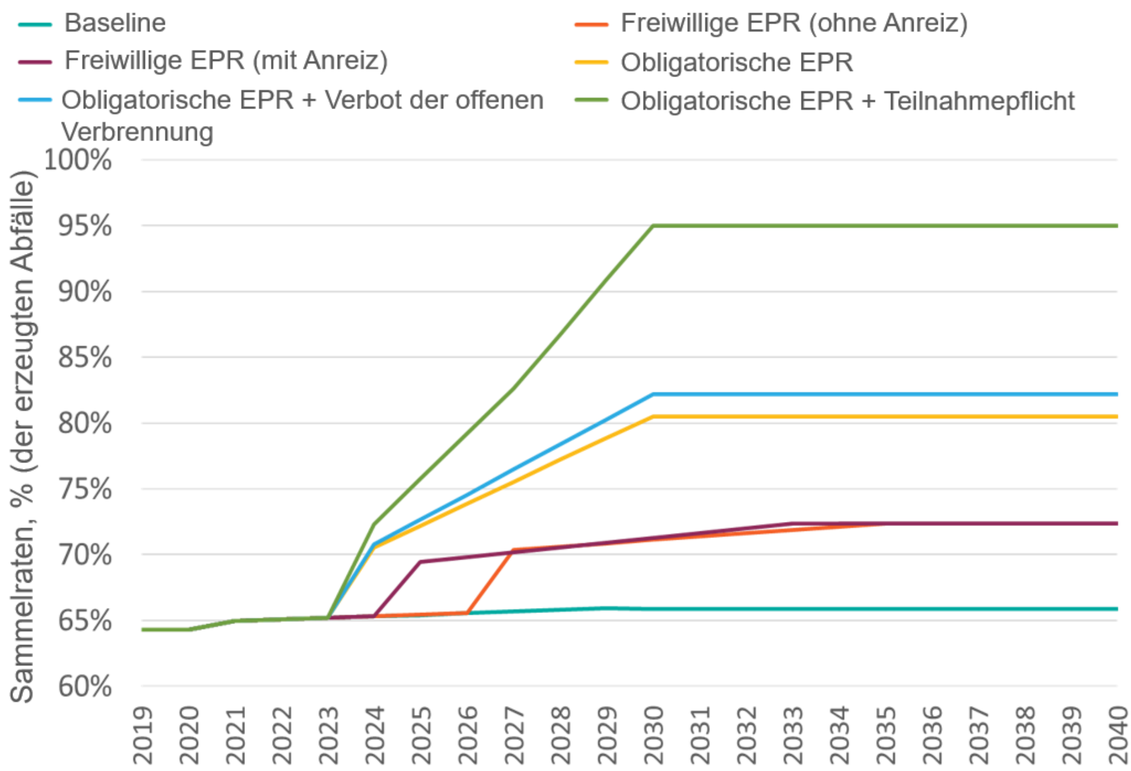
- Die Umsetzung der EPR für Agrarkunststoffe wird wahrscheinlich zu einer erheblichen Verbesserung der Sammel- und Recyclingquote für Agrarkunststoffe in der gesamten EU führen. Als politische Maßnahme ist sie verhältnismäßig und zielgerichtet. Sie wird es den Mitgliedstaaten auch ermöglichen, die Anforderung der getrennten Sammlung von Kunststoffabfällen zu erfüllen, die in der Abfallrahmenrichtlinie (AbfRRL) festgelegt ist und für die die Frist 2015 bereits abgelaufen ist.
- Es werden drei Optionen für die Umsetzung des EPRs in Betracht gezogen: verpflichtend; freiwillig (mit Anreizen) und freiwillig (ohne Anreize). Die verpflichtende EPR ist wahrscheinlich am effektivsten. Es gibt Beispiele für erfolgreiche freiwillige EPR-Systeme für Agrarkunststoffe (z. B. ADIVALOR in Frankreich), aber es ist zu erwarten, dass

freiwillige Ansätze Schwierigkeiten bereiten könnten, die höchsten Sammelquoten zu erreichen.

- Die Kosten für die Abfallbewirtschaftung steigen im Vergleich zum Ausgangswert für alle EPR-Optionen aufgrund einer Verringerung des Volumens der "nicht erfassten" Abfälle (d. h. der Abfälle, die nicht als über ein System zur Sammlung von Agrarkunststoffen gesammelt gemeldet werden). Im Rahmen der EPR werden mehr dieser zuvor "nicht erfassten" Abfälle gesammelt und verursachen daher Kosten für das Abfallmanagement.
- EPR kann mit anderen Maßnahmen kombiniert werden, um die Wirksamkeit weiter zu erhöhen (z. B. ein Verbot der offenen Verbrennung von Agrarkunststoffen oder die Verpflichtung der Landwirte /-innen zur Teilnahme an einem System der getrennten Sammlung).

Abbildung E- 4 zeigt die modellierten Sammelraten bis zum Jahr 2040 unter der Business-as-usual-Baseline, der freiwilligen EPR (sowohl mit als auch ohne Anreiz) und der obligatorischen EPR. Höhere Sammelquoten werden modelliert, wenn die obligatorische EPR mit unterstützenden Maßnahmen kombiniert wird - einem Verbot der offenen Verbrennung von Agrarkunststoffabfällen und einer obligatorischen Verpflichtung für Landwirte/-innen zur Teilnahme an Agrarkunststoffsammelsystemen.

Abbildung E- 4 Sammelraten (2019 bis 2040), %



E.13.0 Empfehlungen

E.13.1 Die erweiterte Herstellerverantwortung (EPR)

In Anbetracht der bestehenden Verpflichtung zur getrennten Sammlung von Kunststoffabfällen gemäß Artikel 11 (1) der AbfRRL wird empfohlen, dass die Europäische Kommission Leitlinien entwickelt, die die Mitgliedstaaten ermutigen, EPR einzuführen, um ihre Verpflichtungen gemäß der AbfRRL in Bezug auf landwirtschaftliche Kunststoffabfälle zu erfüllen. Es wird weiterhin empfohlen, dass solche Leitlinien, aufbauend auf den Ergebnissen der aktuellen Studie, die relativen Vorzüge von freiwilligen gegenüber verpflichtenden Ansätzen, bewährte Verfahren in Bezug auf die Einrichtung und den Betrieb von EPR-Systemen und die Rolle von unterstützenden Maßnahmen wie Teilnahmeverpflichtungen und ein Verbot der offenen Verbrennung von Agrarkunststoffen berücksichtigen.

E.13.1.1 Aufnahme von BAAK in EPR

BAAK sollten in die EPR-Regelung für Agrarkunststoffe aufgenommen werden. Das EPR-System kann als Mechanismus genutzt werden, um Daten darüber zu sammeln, wie und wo BAAK verwendet werden. Es ist vorgesehen, dass BAAK-Hersteller/-innen von der Beteiligung an den EPR-Sammel- und Behandlungskosten befreit würden (da diese nicht für BAAK gelten, die in der Umwelt biologisch abgebaut werden) und stattdessen nur eine Verwaltungsgebühr für die Datenverwaltung zahlen müssten.

E.13.2 Normen für BAAK

Wo eine Norm für BAAK existiert (z. B. EN 17033 für Mulchfolien), wären nur zertifizierte BAAK von den EPR-Sammel- und Behandlungskosten befreit. Dies würde das Risiko verringern, dass Hersteller/-innen von Agrarkunststoffen ihre konventionellen Agrarkunststoffe fälschlicherweise als "biologisch abbaubar" kennzeichnen, um EPR-Gebühren zu vermeiden. Damit die Integration von BAAK in EPR-Regelungen wirksam ist, müsste die betreffende EPR-Regelung eine vollständige Beteiligung der Hersteller/-innen und strenge Anforderungen an die Datenerfassung vorsehen - was bei einem obligatorischen Ansatz am leichtesten zu erreichen ist.

Wenn die aktuelle EN 17033 Norm in EPR-Programmen als Nachweis für die Konformität und die Befreiung von den EPR-Entsorgungskosten herangezogen werden soll, sollte sie überarbeitet werden, um bewährte Verfahren und Unsicherheiten zu berücksichtigen. Derzeit schlägt die Norm vor, dass Landwirte/-innen das Material nach der Wachstumsperiode in den Boden einarbeiten. Dies ist bei einigen Kulturen (z. B. Weinbau) nicht immer möglich (oder keine typische Praxis), weshalb diese Praxis nicht immer eingehalten wird. Es wird empfohlen, keine Ausnahme für eine Kulturart zu gewähren, bei der Landwirte/-innen nicht nachweisen können, dass die Einarbeitung in den Boden erfolgt.

Für Mulchfolien und andere BAAK, die auf der Bodenoberfläche verbleiben, müssen eine neue Norm und ein zugehöriges Prüfverfahren entwickelt werden, um einen Rahmen zu schaffen, der es diesen Produkten ermöglicht, von EPR-Ausnahmen zu profitieren. Darüber hinaus sollten BAAK-Produkte, für die es keine überprüfte und akzeptierte Norm gibt, als "schlecht verwaltet" betrachtet werden, wenn sie in der Umwelt verbleiben, so wie es derzeit bei herkömmlichen Kunststoffen der Fall ist.

E.13.3 Obligatorische Mindestdicke für konventionelle Mulchfolien

Eine verbindliche Mindestdicke/Zugfestigkeit für konventionelle Mulchfolien könnte das Risiko des Reißens während des Entfernungsprozesses (und der anschließenden Anreicherung von Kunststofffragmenten in der Umwelt) minimieren. Derzeit gibt es nur sehr wenige quantitative Nachweise, die einen Zusammenhang zwischen spezifischen Mulchfoliendicken und dem Anteil an Kunststoff, der nach der Entfernung in der Umwelt verbleibt, herstellen. Die europäische Norm für "Nach Gebrauch rückbaubare thermoplastische Mulchfolien für den Einsatz in Landwirtschaft und im Gartenbau“ (EN 13655) legt fest, dass die Mindestdicke für schwarze Mulchfolien 20 - 25µm betragen sollte. Die Norm ist jedoch nicht verpflichtend; der Anteil der Mulchfolienprodukte, die der Norm entsprechen, ist nicht bekannt, obwohl davon ausgegangen wird, dass möglichst dünne Folien (~10 µm) als "kostensparend" vermarktet werden, obwohl dies längerfristig am falschen Ende sparen würde, wenn dies zu höheren Raten der Anhäufung von Folien im Boden führt, was das Risiko erhöht, dass die Erträge negativ beeinflusst werden.

Es ist daher von entscheidender Bedeutung, dass weitere Untersuchungen durchgeführt werden, um die Beziehung zwischen Foliendicke und Folienentfernung besser zu verstehen und, um herauszufinden, ob EN 13655 ausreicht, um diese zu beschreiben, bevor eine verbindliche Mindestdicke (oder Festigkeit) empfohlen wird; danach könnte EN 13655 als verbindliche Spezifikation dienen. Dies und eine Reihe anderer Bereiche für weitere Forschung werden in E.13.4 empfohlen.

E.13.4 Weitere Forschung

In dieser Studie gab es einen bemerkenswerten Mangel an verifizierbaren Daten, aus denen Schlussfolgerungen gezogen werden konnten. Daher werden folgende Datenlücken und weiterer Forschungsbedarf hervorgehoben:

Datenlücken

- Es fehlen statistische Daten über die Mengen der in Verkehr gebrachten Agrarkunststoffe, ihre Verwendungszwecke und ihr Verbleib am Ende der Lebensdauer auf der Ebene der Mitgliedstaaten.
- Ein Großteil der Forschung und der veröffentlichten Erkenntnisse über biologisch abbaubare Mulchfolien basiert auf den Erfahrungen aus Südeuropa, insbesondere aus Italien. Veröffentlichte Daten für Nordeuropa gibt es nicht, und das für diese Studie entwickelte Akkumulationsmodell basierte auf Beobachtungen aus einer US-Studie.
- Die Migration von Kunststoffresten in andere Umgebungen (z. B. Wasserwege) aus konventionellen oder biologisch abbaubaren Mulchen, die in den Boden eingearbeitet werden, wurde bisher weder untersucht noch quantifiziert.
- Es gibt keine überprüfbaren Daten über die typische Menge an konventioneller Mulchfolie, die nach dem Einsammeln auf dem Feld verbleibt. Es wurden zwar verschiedene Zahlen von Interessenvertreter/-innen genannt (von 60-100 % Entfernung), aber dies ist nicht durch empirische Daten bestätigt.
- Es gibt keine überprüfbaren Daten (nur Expertenmeinungen) über den Zusammenhang zwischen der Mulchfoliendicke und der typischen Menge an konventioneller Mulchfolie, die nach dem Einsammeln auf dem Feld verbleibt.

- Es gibt keine Untersuchungen über das Ausmaß der schädlichen Auswirkungen, die mit dem Verbleib von Agrarkunststoffen in der Umwelt verbunden sind.

Querschnittsempfehlungen für weitere Forschung

- Aufbau eines robusten und genauen Überwachungsdatensystems für Kunststoff in der Landwirtschaft. Die Datenerfassung im Rahmen der EPR könnte diese Daten liefern, deren Abdeckung optimal wäre, wenn die EPR-Systeme verpflichtend wären.
- Entwicklung eines räumlichen Modells der potenziellen Abflüsse von landwirtschaftlichen Flächen in die Wasserstraßen, welches die Lage der Betriebe in Bezug auf die Wasserstraßen, die Bodenerosion und Regenereignisse berücksichtigt.

Empfehlungen für die weitere Forschung zu konventionellen Agrarkunststoffen

- Beauftragung einer feldbasierten Studie, die sich auf die Bestimmung typischer und optimaler Praktiken für die konventionelle Mulchfolienentfernung konzentriert. Dabei sollten Variablen wie Kulturpflanzenart, Materialstärke und Entfernungsgeräte berücksichtigt werden.
- Bestimmung, ob die bestehenden Anforderungen in der Europäischen Norm "Nach Gebrauch rückbaubare thermoplastische Mulchfolien für den Einsatz in Landwirtschaft und im Gartenbau " (EN 13655) ausreichen, die, wenn sie verpflichtend gemacht werden, zu einer größeren Entfernung von konventionellen Mulchfolien aus dem Boden führen werden.
- Entwicklung weiterer politischer Optionen zur Durchsetzung/Förderung guter Praktiken, sobald ein Datensatz sowohl für typische als auch für optimale Praktiken zur konventionellen Mulchfolienentfernung erworben wurde. Diese könnten u. a. umfassen:
    - Anforderungen an bestimmte Entnahmegeräte
    - Leitfaden für bewährte Verfahren
    - Anforderungen an die Ausführung der Mulchfolie, z. B. Mindestdicke
    - Einschränkung von konventionellen Mulchfolien für bestimmte Anwendungen (z. B. für Kulturarten, bei denen eine vollständige Entfernung von konventionellen Mulchfolien nachweislich nicht möglich ist)
- Eine Beurteilung der Wirksamkeit von mechanischen Mulchfolien-Entfernungstechniken (z. B. die in Frankreich erprobte RAFU-Technologie) bei der Verringerung der Kontamination und davon, ob Maßnahmen zur Unterstützung des Einsatzes dieser Technologie umgesetzt werden sollten.

Empfehlungen für die weitere Forschung zu biologisch abbaubaren Agrarkunststoffen

- Die Durchführung weiterer Studien zur Verwendung von biologisch abbaubaren Mulchfolien, die den Boden über mehrere Wachstumsperioden in verschiedenen Klimazonen beproben. Die Ergebnisse dieser Untersuchungen müssen ggf. in eine Aktualisierung der EN 17033 einfließen.
- Die Entwicklung einer Standardtestmethode für die biologische Abbaubarkeit und damit verbundene Grenzwertanforderungen für bestimmte Produkte, die auf dem Boden verbleiben (anstelle der bestehenden Tests für im Boden), z. B. für Baumschutzprodukte.

- Neben der Identifizierung, wo bestimmte konventionelle Mulchfolienanwendungen die Entfernung aus dem Boden verhindern, können diese Anwendungen von Anreizen für die Verwendung von biologisch abbaubaren Mulchfolien profitieren.

Contents

Glossary

The following are some of the key terms that are used throughout this report.

Agri-plastics	APE Europe defines agri-plastics as non-packaging plastics products that have a direct agronomic effect on the crop or on its conservation such as irrigation pipes, drainage tubes, films and covers, forage twine and nets, shading and protecting nets, etc.[1] It should be noted that the term 'plasticulture' is also often used interchanged with agri-plastics, which refers to the practice of using plastic materials in agricultural applications.
Bio-based plastics	Bio-based plastics are those with building blocks that are derived partly or wholly from plant-based feedstocks. These are often also known as bioplastics.
Biodegradable plastics	Biodegradable plastics are those that can be decomposed by the action of living organisms e.g. microbes into water, carbon dioxide, and biomass. Biodegradable plastics are commonly produced with renewable raw materials, micro-organisms, petrochemicals, or combinations of all three.
Biodegradation[2]	Biodegradation is a process by which material disintegrates and is decomposed by microorganisms into elements that are found in nature, such as CO^2, water and biomass. Biodegradation can occur in an oxygen rich environment (aerobic biodegradation) or in an oxygen poor environment (anaerobic biodegradation).
Composting[2]	Composting refers to enhanced biodegradation under managed conditions, predominantly characterised by forced aeration and natural heat production resulting from the biological activity taking place inside the material. The resulting output material, compost, contains valuable nutrients and may act as a soil improver.
Conventional plastics	Plastic derived from fossil-based feedstocks that is not considered to be biodegradable or compostable in any reasonable timeframe.
Oxo-degradable plastics[2]	Conventional plastics, which include additives to accelerate the fragmentation of the material into very small pieces, triggered by UV radiation or heat exposure. Due to these additives, the plastic fragments over time into plastic particles, and finally microplastics, with similar properties to microplastics originating from the fragmentation of conventional plastics.

[1] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics
[2] European Commission (2018). Report from the Commission to the European Parliament and the Council on the impact of the use of oxo-degradable plastic, including oxo-degradable plastic carrier bags, on the environment. Retrieved at : https://ec.europa.eu/environment/circular-economy/pdf/oxo-plastics.pdf

Abbreviations

The following table provides a list of the acronyms and abbreviations used in this report.

APW	Agri-plastic waste
BDAP	Biodegradable agricultural plastics
BDM	Biodegradable mulch films
EPR	Extended producer responsibility
EC	European Commission
EOL	End-of-life
GRP	Glass reinforced polyester
HDPE/LDPE	(High density) (Low Density) Polyethylene
MS	Member State
PA	Polyamides
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PCL	Polycaprolactone
PE	Polyethylene
PEF	Polyethylenefuranoate
PET	Polyethylene Terephthalate
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
PMMA	Polymethylmethacrylate
PP	Polypropylene

1.0 Introduction

This report has been prepared for DG Environment of the European Commission by Eunomia Research & Consulting Ltd and its partners, Deloitte and ENT. It represents the final deliverable for Service Request Number 10 under Framework Contract No. ENV.B1/FRA/2018/0002 Lot 1 on:

Conventional and Biodegradable Plastics in Agriculture.

According to the study Terms of Reference, the overall objective of this study is to support the Commission's work on potential policy actions regarding agricultural plastics, and in the establishment of a framework for biodegradable plastics. In particular, the objective is to identify and reduce the environmental impacts associated with conventional and biodegradable agricultural plastics, where the main focus should be on their end-of-life, i.e. their improper collection, low reuse and low recycling on the one hand and their effective biodegradability on the other hand.

1.1 Context

The use of plastic materials in agriculture (hereafter referred to as “agri-plastics”) was first introduced in 1948 in the USA to cover small greenhouses with cellophane and, shortly after, polyvinylchloride (PVC) to cover greenhouses in Japan. The use of plastics has progressively expanded over the years in many countries, replacing traditional materials such as glass to cover greenhouses and paper or straw for soil mulching.

Today, plastic materials are widely used in the European agricultural sector, which has been driven by increased demand and productivity. The benefits of agri-plastic applications include increased yields, earlier harvests, less reliance on herbicides and pesticides, frost protection and water conservation, etc. In addition to the increase in quality, efficiency and quantity of agricultural production, agri-plastic applications can also contribute to a more effective use of farm land. As such, their use is steadily increasing, particularly for specific applications, notably films used to cover greenhouses and tunnels in countries such as Italy, Spain and France. Likewise, the use of mulching films for soil conditioning is also on the rise.

In 2018, PlasticsEurope estimated that the agricultural sector accounted for approximately 3.4% (1.7 million tonnes) of the total demand for plastics in Europe. Agriculture Plastic & Environment Europe (APE Europe) estimated that in 2019, approximately 722 K tonnes (kt) of agri-plastic applications (excluding packaging) were placed on the European market.[3] It should be noted that the market figures reported by

[3] Based on data provided by APE Europe.

PlasticsEurope are higher due to a broader scope, which includes particular agricultural plastic packaging applications, whereas APE Europe figures specifically refers to the main **non-packaging** agri-plastic applications used in Europe e.g. agricultural films and covers, irrigation pipes, twine and nets.

Despite their important benefits, agri-plastics can also generate significant adverse effects across their life-cycle on the environment and human health. This includes negative impacts stemming from the manufacturing process (e.g. use of plastic materials, energy and water resources) as well as at end-of-life when products are improperly disposed of. Agri-plastics use is generally concentrated geographically in specific areas of high agricultural productivity within Europe. This can result in significant plastic pollution, but also presents important opportunities for improving and increasing the collection and recycling of agricultural plastic waste (APW). Further, certain APW streams (e.g. homogeneous in composition; not highly contaminated) can also be used as new secondary raw materials, which can facilitate recycling and increase its value for recyclers. Plastics that biodegrade in soil within a short time frame also offer a potential route for minimising the negative environmental effects of conventional plastic at end of life.

Further efforts are therefore needed at EU level to not only build on the potential opportunities to increase recycling markets and contribute to the transition towards a circular economy, but also to address the lack of agricultural plastic waste management schemes in most MS and the inefficiency (technical and/or economic) of existing programmes.

1.2 Layout of the Report

The report is structured as follows:

- Section 2.0 provides quantitative details on agri-plastics consumption and end-of-life management;
- Section 3.0 focuses on issues relating to the end-of-life management of conventional agri-plastics;
- Section 4.0 focuses on issues relating to the end-of-life management of biodegradable agri-plastics;
- Section 5.0 presents the forward-looking baseline of agri-plastics consumption, waste generation and management;
- Section 6.0 identifies objectives and potential policy measures;
- Section 7.0 provides a more in-depth discussion of the selected policy measures;
- Section 8.0 presents the modelled performance of different policy measures; and
- Section 9.0 provides a comparison of the policy options.

Further detail is provided in the technical appendices.

2.0 Quantifying Agri-Plastics Consumption and End of Life Practices

This chapter provides an overview of the EU agri-plastics sector, covering the following aspects:

- Categorisation of agri-plastics (including both conventional and biodegradable plastics) by main applications, polymers used, etc.
- Existing policy measures
- Consumption trends: volumes, geographic distribution, share of conventional versus biodegradable plastics, use of recycled material, etc.
- End-of-life (EOL) management practices: collection, re-use, recycling, landfilling, energy recovery, burning / burial on site
- Existing policies on agri-plastics at EU, Member State (MS) and international level

A detailed summary of the methodology and approach applied for the state of play of agri-plastics is provided in Section A.1.0 of the appendix.

2.1 Scope and geographic coverage

The scope of the study covers conventional and biodegradable plastics used in agricultural applications that are placed on the market, with a specific focus on horticulture and livestock farming. The intentional use of microplastics, for example, in applications such as seed coatings, slow-release and controlled-release fertiliser polymers are not included in the scope of the study. The overview covers key trends at international, European, national and sector-specific level (where relevant) with particular focus on a representative selection of EU Member States (MS) (Table 2-1) and third countries. The selection of MS for detailed analysis reflects:

- Availability of relevant data and information
- Geographic representativeness
- Existence of national collection and/or recycling schemes[4]
- Agri-plastics consumption at national level

In addition to the focus on a representative selection of MS, an overview of international practices and key trends is also provided, with a specific focus on Canada, Iceland, Norway and the UK; countries with established collection and/or recycling schemes and/or relevant national policies and initiatives.

[4] CPA website: "European regulation – National Collecting Schemes". Accessible at: www.plastiques-agricoles.com/ape-europe-missions/agricultural-plastics-european-regulation

Table 2-1: Selection of representative MS

EU Member States		
• Bulgaria • Greece • France* • Finland	• Germany* • Ireland* • Italy* • Netherlands	• Poland • Spain* • Sweden*

**Countries with established national/regional collection schemes*

2.2 Categorisation of agri-plastics

In order to develop an inventory and categorisation of agri-plastics in the EU, the first step is to identify the main agri-plastics applications observed across the sector. For each of the principal identified applications, a list of the main types of polymers is then established. Where relevant, polymers are also classified as either conventional or biodegradable.

2.2.1 Plastics in agricultural applications

The use of plastics for agricultural purposes is well-established within in the EU. Some of the reported benefits of using plastic materials in agricultural fields include increased yields, earlier harvests, reduced use of agrochemicals (e.g. herbicides and pesticides) and water conservation. The use of agricultural plastic also contributes to a more efficient use of farm land and higher quality of crops. Furthermore, plastics-based agricultural systems provide effective solutions to crop growing in arid regions, by cutting irrigation costs by one to two-thirds, while as much as doubling crop yield.

Based on relevant findings from literature[5,6] Table 2-2 provides an overview of the main agri-plastic applications. It should be noted that overall, there is very limited innovation in regard to the use of agri-plastics in new applications. Principle innovations relate to the development of effective additives to enhance the durability of plastics, improve crop productivity and quality, and optimise the environmental impacts of such products. New applications for biodegradable plastics are also being investigated more recently. While the report referenced in Table 2-2 is from 2012, the range of applications described applies equally to the situation in 2020.

Applications can be categorised in relation to their intended function/purpose:

- **Films for crop protection (not in direct contact with soil)**: this product category is by far the largest group of plastics used in agriculture. The main purpose of using crop protection films is to increase yield and to extend the cropping season by protecting

[5] PlasticsEurope website on Plastics in agricultural applications. Accessible at: www.plasticseurope.org/en/about-plastics/agriculture

[6] Scarascia, G. et al. (2012) "Plastic materials in European agriculture: Actual use and perspectives" Journal of Agricultural Engineering, Vol. 42, No.3

plants from atmospheric agents and to keep the ideal temperature and moisture levels for growth. The most important applications are greenhouses and large tunnels, low tunnel covers and direct covers mainly for vegetable protection but also for fruit, flowers, mushrooms and nursery stock. Greenhouses are used for melons, watermelons, strawberries, tomatoes, cucumbers, lettuce, eggplants, peppers, flowers, ornamental plants nursery and low tunnels are used for strawberries, melons, watermelons, vegetables, and carrots. Direct covering is used for leaf and root vegetable crops, table grape vineyards, tobacco, tomatoes, potatoes, melons, water melons, and strawberries.


- **Films for soil conditioning (in direct contact with soil)**: this category refers to the mulching technique which consists in covering the soil with plastic films in order to limit growth of weeds, reduce moisture removal and maintain warmth. The types of films used for mulching can be distinguished by colour; transparent materials enable rapid heating of the soil as well as conserving moisture and protecting the soil, whereas black materials are effective at preventing weed growth. Reflective films, opaque white or metallised, can also be used in particular in low light conditions to concentrate sunlight onto the plants to increase photosynthesis. Mulching is mainly used for tomatoes, lettuce, marrow, onion, aubergine, beans, strawberries, watermelon, melon, and asparagus and can also be combined with polytunnels.


- **Silage films and protective covering (including stretch film)**: these applications are used to store and preserve silage, hay and maize grasses for use as animal feed. The most important features of silage film are the barrier properties against air and water which allows the feed to ferment anaerobically and therefore preserve it longer. There are generally two types of systems using these films; individual, in which the feed is baled and wrapped and in silage 'clamps' where the feed is piled up in an open concrete structure, compacted down and then covered with the plastic sheet.

Source: Mike Faherty (under Creative commons licence)

- **Netting and twine**: netting can be characterised based on the material types: non-woven and woven nets. Woven netting is widely used to protect crops from hail, wind, snow, or strong rainfall, but also for shading for greenhouse applications during warmer seasons to cool the inside microclimate, while non-woven nets are used for harvesting and post-harvesting operations such as bale nets. In terms of crop types, woven netting is commonly used to protect fruit, in particular soft fruits, from birds and to shade mushroom-beds and non-woven for collection at olive farms. Twines are mostly used in vegetable packing, fruit packing, and to bind bales.

Source: (L) Flominator, (R) Rhian de Kerhiec (under Creative commons licence)

- **Plastics for water management**: refers to applications used for water collection, storage, transport, water holding/ drainage and for irrigation systems. Irrigation pipes are the most used products in this category, in particular for crop production.

Table 2-2: Main Agri-plastic Applications

Product categories	Intended purpose	Specific applications
Covers and films	Crop protection (not in direct contact with soil)	• Greenhouses and large tunnels • Low tunnels • Nursery films • Direct covers • Covers for vineyards, orchards
	Soil conditioning (in direct contact with soil)	• Mulching films
	Protection and storage of animal feed e.g. forage, silage, hay and maize	• Silage films • Bale wraps • Silage bags • Stretch films
Netting and twine	Crop protection Collection and storage of crops	• Bale twines • Non-woven nets (e.g. olives and nut collection) • Bale nets • Protective nets (windbreaks/anti-hail/ anti-bird/ shading)
Irrigation systems	Water management	• Irrigation pipes and drippers • Drainage tapes and channel lining
Receptacles, bags and containers	Harvesting, packaging, transportation and storage of crops and plant protection products	• Pesticide containers • Fertiliser sacks • Liquid tanks • Storage crates

Source: Scarascia (2012); PlasticsEurope

2.2.2 Polymers and additives used in agri-plastic applications

2.2.2.1 Polymers

Approximately twenty distinct groups of plastic polymers are used in existing agri-plastic applications and can be classified as either conventional or biodegradable plastic polymers, each with various formulations corresponding to specific applications and their intended purpose.

Conventional plastics refers to plastic derived from fossil-based feedstocks that is not considered to be biodegradable or compostable in any reasonable timeframe.

In accordance with Article 3(16) of Directive 2019/904 on the reduction of the impact of certain plastic products on the environment (commonly referred to as the Single Use Plastics (SUP) Directive), **biodegradable plastics,**

> *"…means a plastic capable of undergoing physical, biological decomposition, such that it ultimately decomposes into carbon dioxide (CO_2), biomass and water, and is, in accordance with European standards for packaging, recoverable through composting and anaerobic digestion"*

Article 15 (evaluation and review) adds that an evaluation should be carried out, including:

> *"an assessment of the scientific and technical progress concerning criteria or a standard for biodegradability in the marine environment applicable to single-use plastic products within the scope of this Directive and their single-use substitutes which ensure full decomposition into carbon dioxide (CO2), biomass and water within a timescale short enough for the plastics not to be harmful to marine life and not to lead to an accumulation of plastics in the environment."*

It should be noted that although the definition for biodegradable plastics provided under the SUPD describes the describes the process of biodegradation in broad terms, a timeframe and method to test for biodegradation are not further specified, but reference is given to *European standards for packaging, recoverable through composting and anaerobic digestion* which refers to EN 13432 which applies specifically to biodegradation criteria and testing in an industrial composting setting.

Current European standards on the compostability of packaging and non-packaging plastics (EN 13432 and EN14995, respectively) and mulch films for use in agriculture and horticulture (EN 17033) define (ultimate) biodegradation as the following:

> *"[The] breakdown of an organic chemical compound by micro-organisms in the presence of oxygen to carbon dioxide, water and mineral salts of any other elements present (mineralization) and new biomass or in the absence of oxygen to carbon dioxide, methane, mineral salts and new biomass".*

Importantly, the terms *bio-based* and *fossil-based* relate to the raw material feedstocks that are used to produce plastics. This is entirely separate from the way in which the material behaves in the environment; **not all bio-based plastics are compostable or biodegradable; and not all compostable or biodegradable plastics are bio-based.** The terms bio-based and biodegradable are therefore not synonyms. The term 'bioplastic' is also often used but the terms of bio-based, biodegradable or compostable help to remove some of the ambiguity. It is possible and becoming increasingly common for conventional plastics such as polyethylene (PE) to be made, at least in part, from a bio-based feedstock. This has no noticeable effect on the end product and is chemically identical to its fossil-based counterpart and can therefore be recycled in the same way and is not biodegradable.

There are many kinds of material that claim to be biodegradable, or even just degradable, but the reality of such assertions is questionable. 'Oxo-degradable', 'oxy-degradable' or 'oxo-biodegradable' plastics are a key example, and they should not be confused with the biodegradable plastics discussed in this report. They are conventional plastics such as polyethylene (PE) which contain an additive designed to help them fragment.

Manufacturers claim that these materials fragment and degrade in the presence of oxygen. This leads to fragmentation, making the material more bioavailable for microorganisms to supposedly aid degradation. There is little evidence in practice for full biodegradation of these materials within a meaningful timeframe.[7]

Because of this, the SUP Directive explicitly placed a ban on all products made from oxo-degradable plastic and Member States are required to comply with this by 3rd July 2021. However, agri-plastic consumption data used in this report still shows use of this material for mulch film applications in small quantities.

Figure A2.1 in the appendix lists the main polymers used in agri-plastic applications. As shown in the table, the main conventional polymer used in agri-plastic applications is **polyethylene** (PE), a thermoplastic polymer belonging to the polyolefin family. PE exists in two main forms: high density polyethylene (HDPE = 0.94-0.96 g/cm^3) and low density polyethylene (LDPE = 0.92-0.93 g/cm^3). Linear low density polyethylene (LLDPE) is also used in order to produce films where high flexibility and extra strength is required. PE has a wide range of agricultural uses because of its low cost, versatility and chemical resistance. In particular, LDPE is used to produce **agricultural films** (for greenhouses, low tunnels, mulching, and silage) and irrigation tapes, while HDPE is generally used to produce nets and sometimes irrigation pipes.

Polypropylene (PP) is the second most common linear thermoplastic polymer of the polyolefin family used for agricultural purposes. In comparison to LDPE and HDPE, PP has a lower impact strength, but greater working temperature and a higher resistance to breaking under tension. PP is most widely used as fibres and filaments produced by extrusion and is used in agriculture mainly for twines, and for piping, sheeting, and nets to a lesser extent.

Biodegradable polymers are increasingly being used as alternative substitutes for several applications in agriculture, particularly for mulching. These products have been introduced in the agricultural sector to help reduce the negative impacts of conventional plastics. The most common biodegradable polymers used as an alternative to conventional plastics in agriculture are starch blends, polybutylene adipate terephthalate (PBAT), polybutylene succinate (PBS), polylactic acid (PLA) and polyhydroxyalkanoate (PHA).

2.2.2.2 Additives

In many agri-plastic applications, various chemical substances (known as “additives”) are used to enhance the functional and technical properties of plastic products and prolong their useful life. Some of the most commonly used additives in different types of plastic products include: plasticisers, flame retardants, antioxidants, light and heat stabilisers,

[7] Eunomia Research & Consulting (2016) The impact of the use of ‘oxo-degradable’ plastic on the environment : final report. September 2016. Available at: https://publications.europa.eu/en/publication-detail/-/publication/bb3ec82e-9a9f-11e6-9bca-01aa75ed71a1

lubricants, pigments, antistatic agents, slip compounds and thermal stabilisers.[8] For agricultural films in particular, light stabilisers and UV absorbers are frequently used to prevent early degradation of agricultural plastics by making them resistant to sunlight, heat and in some cases ensure resistance against significant use of agriculture chemicals for crop treatment.[9] It should be noted that additives are sometimes used in both conventional and biodegradable plastics depending on the type of application and product characteristics. For example, carbon black is used in both material types for mulching films to provide UV resistance and pigment. Figure A2.1 in the Appendix provides additional details on the use of specific additives in agri-applications.

Despite the improved performance that additives can bring to agri-plastic applications, their potential to contaminate soil, air, water and food is widely documented in literature. For example, additives can potentially migrate and lead to human exposure via e.g. food contact materials, such as packaging.[10] Furthermore, additives from agri-plastic applications can also be released during various recycling and recovery processes as well as from products manufactured from recyclates. This can create additional challenges for sound recycling processes, which would need to ensure that the emission of substances of high concern and contamination of recycled products is avoided.

At EU level, the use and emissions of certain additives are regulated under the REACH Regulation. Biodegradable mulch films that conform with EN 17033 must also not contain any substance of very high concern (SVHC) as any chemicals used in the product are directly emitted into soil during biodegradation. Currently there is no officially reported data at EU level on the quantities of additives used in agri-plastic applications.

2.3 Key stakeholders

Understanding the dynamics of the agri-plastics sector in Europe is of particular importance when considering potential options at EU level to further increase collection and recycling. In Europe, agri-plastic applications are used for a multitude of purposes across the different life-cycle stages of the agricultural supply chain. The main actors involved across the life cycle of agri-plastics in Europe include:

- **Plastic converters**: produce and place agri-plastics on the European market taking into account relevant regulatory provisions, in particular the use of certain additives.
- **Farmers and growers**: end-users of agri-plastics for agricultural production, in charge of the final disposal practices at end-of-life.

---

[8] Hahladakisa, John et al. (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*. Volume 344, 15 February 2018, Pages 179-199

[9] BASF website on plastic additives used in agriculture. Accessible at : www.plasticadditives.basf.com/ev/internet/plastic-additives/en_GB/content/plastic-additives/Industries/Agriculture/index

[10] Hahladakisa (2018) "An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling

- **National, regional public authorities**: responsible for the transposition of EU legislation, monitoring and enforcement, knowledge exchange and information provision.
- **Waste management operators, including plastic recyclers**: ensure end-of-life treatment, data reporting, compliance with relevant EOL treatment requirements, etc.

The stakeholder engagement process and the main stakeholders with which Eunomia and its partners engaged are described in A.1.1.2.

2.4 Existing Policy Measures at EU and national level

There is currently no overarching legislation at EU level, which specifically regulates the management of agricultural plastic waste. However, several provisions in the following existing EU legislation address agri-plastics to some extent:

- **Waste Framework Directive (WFD)** (Directive 2008/98/EC on waste as amended by Directive 2018/851): establishes the main provisions on waste management in the EU. The overall objective of the WFD is to reduce the environmental impact of waste and encourage resource efficiency through reuse, recycling and recovery. The WFD further lays out general guiding principles e.g. waste hierarchy, polluter pays principle, extended producer responsibility, etc. and also prohibits uncontrolled discarding of waste.

  While specific end of life management requirements for agricultural plastic waste are not further detailed in the WFD, Article 11 (1) states that:

  > *"Member States shall take measures to promote high quality recycling and, to this end, shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors. Subject to Article 10(2), by 2015 separate collection shall be set up for at least the following: paper, metal, plastic and glass."*

  Furthermore, Article 10 (4) of the WFD states that such separately collected waste should not be incinerated:

  > *"Member States shall take measures to ensure that waste that has been separately collected for preparing for re-use and recycling pursuant to Article 11(1) and Article 22 is not incinerated, with the exception of waste resulting from subsequent treatment operations of the separately collected waste for which incineration delivers the best environmental outcome in accordance with Article 4."*

  The above-mentioned obligations, however, appear to have had limited impact as there are several Member States without separate collection for agri-plastics in place. Likewise, while the WFD Preamble (29) of the WFD provides that "*Member States should support the use of recyclates, such as recovered paper, in line with the waste hierarchy and with the aim of a recycling society, and should not* *support the landfilling or incineration of such recyclates whenever possible*.", there is no specific provisions laid out regarding the landfilling of plastic waste.

- **EU Plastics Strategy**: sets out measures to increase plastics recycling and reuse, including rules to harmonise the implementation of EPR schemes across the EU.
- **Single-use Plastics Directive** (Directive 2019/904): Article 5 prohibits Member States from placing products made from oxo-degradable plastic on the market.
- **REACH Regulation** (Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals): sets requirements related to recovery operations, including mechanical processing[11], the use of recycled material, and the use of legacy additives such as cadmium and lead stabilisers.[12]
- **Incineration Directive** (Directive 2000/76/EC): forbids uncontrolled burning of waste, including bio-waste.
- **Landfill Directive** (Directive 99/ 31/EC): forbids the uncontrolled burying of waste.

Table 2-3 provides an overview of national measures that specifically address the open burning of agricultural plastic waste in fields. Further details on other relevant measures at national level are provided in the Section 2.6 and in Appendix A.2.2.

While the EOL management of agri-plastic waste (with the exception of packaging) is not currently directly addressed by specific EU legislation, some Member States have established their own national regulations with regards to the recovery of agri-plastics, placing physical and financial responsibility on manufacturers and distributors to collect and process agri-plastic waste and prohibiting the open burning of agri-plastic waste.

[11] Plastics Recyclers Europe website on REACH. Accessible at: www.plasticsrecyclers.eu/reach-plastics-recyclers

[12] EPPA website on REACH. Accessible at: https://eppa-profiles.eu/activities/regulatory-affairs/reach

Table 2-3: National Initiatives on Open Burning of Agricultural Plastic Waste

Country	Initiative
Austria	• In Austria, waste management is regulated at the federal level in accordance with the Waste Management Act (Abfallwirtschaftsgesetz – AWG), and the Act on the Prevention of Air Pollution (Bundesluftreinhaltegesetz – BLRG). Local ordinances can also be issued at regional level that can modify certain national level requirements on waste management. In particular, in 2010, provisions of Bundesluftreinhaltegesetz prohibits both the one-off and the area-wide burning of materials outside designated facilities.
Belgium	• Article 7 of the 27 June 1996 – Waste Directive' (MB 02.08.1996) prohibits the open burning / bonfires of waste. The Directive defines waste as any substance or object which the holder discards or intends or is required to discard and as such is applicable to agricultural plastic waste.[13] • In Flanders, Vlarem, the Flemish environmental legislation prohibits the open burning of all waste. However, Vlarem specifies a few exceptions, notably the incineration of waste resulting from agricultural activities if the removal or processing of said waste on site is not possible.[14]
Finland	• In Finland, in accordance with the Environmental Protection Act (527/2014) restrictions and bans on on-farm burning of agricultural plastic waste have been established since 2016.[15]
France	• In France, under the provisions of Article 84 of the Règlement Sanitaire Départemental, the open burning of any waste is prohibited. In addition, Article R543-67 of the Environment Code prohibits the burning or burial of waste plastic packaging on farms, mixing of professional waste in household waste streams and, if hazardous, require disposal at authorized facilities.[16,17]
Germany	• In Germany, waste legislation is regulated at federal level through the Circular Economy Act (Kreislaufwirtschaftsgesetz – KrWG), which forbids the burning of agricultural waste, however, it does not explicitly prohibit the burning of bio-waste.
Ireland	• In Ireland, the burning of agricultural plastic waste is an illegal practice and is an offence under the Air Pollution Act (1987) and the Waste Management (Prohibition of Waste Disposal by Burning) Regulations (2009).
Sweden	• In Sweden, burning of waste is regulated in the Environmental Code (1998:808), the Waste Ordinance (2011:927) and within municipal waste management scheme in some regions. It is forbidden to burn waste without a permit and applies to both households and business operators. • It is also illegal to landfill sorted burnable waste since 2002 (SFS 2001:512). The aim of the bans is to improve resource conservation and reduce environmental impact. To further facilitate recycling, a requirement for sorting burnable waste at source was also introduced in 2002.[18]

---

[13] Clean Air Action Group (2018) Agricultural and Garden Waste Burning Legislation in European Countries. Available at: www.levego.hu/site/assets/files/4883/agricultural_waste_burning_legislation_final.pdf
[14] Available at: https://navigator.emis.vito.be/mijn-navigator?woId=62334
[15] Based on questionnaire responses and interview with Brahea Centre – University of Turku, April 2020
[16] FAO (2008) International Code of Conduct on the Distribution and Use of Pesticides: Guidelines on Management Options for Empty Pesticide Containers. Available at: www.fao.org/3/a-bt563e.pdf
[17] Ademe (2017) "Le brûlage des déchets à l'air libre". Available at: www.loiret-nature-environnement.org/images/D%C3%A9chets/brochureBrulage.pdf
[18] Available at: www.naturvardsverket.se/Documents/publikationer/620-1249-5.pdf

Country	Initiative
UK	• In the UK, burning or burial of APW on site is prohibited under the Waste Management Regulations of 2006. • In Scotland, the burning and burying of farm plastics has been banned since January 2019.[19] The requirement affects in particular silage wrap, crop covers, fertiliser bags and containers. Previously, farmers were allowed to burn agricultural plastics under an exemption to the environmental regulations that had been updated in 2013.

2.5 Agri-plastics Market and EOL Practices at EU level

This section presents an overview of the agri-plastic sector at EU level, covering key consumption and market trends as well as end-of-life (EOL) practices.

2.5.1 Agri-plastics Consumption

According to APE Europe, in 2019 the total volume of agri-plastic applications (excluding packaging) placed on the European market was around 722 kt. Of this amount, livestock farming accounted for 55% of the market, and the remaining 45% for crop production. Ten countries represented 80% of the EU market for non-packaging agri-plastic applications: Italy, Spain, France, Germany, UK, Poland, the Netherlands, Ireland, Sweden, and Belgium.

Between 2015 and 2019, the consumption of agricultural plastics in Europe increased by approximately 7%.[20] The increase in agri-plastics consumption over the past decade has been driven by the introduction of innovative and 'eco-friendly' products, including improved technical product characteristics and functionalities, in the context of an oversupplied market. Other factors such as the decline in available agricultural land and the demand for high-quality crops are also important drivers for the continued use of agri-plastics. Nonetheless, it is important to note that the agricultural sector accounts for a relatively small share of the total EU plastics demand, which has been reported to represent about 1.4%[21].

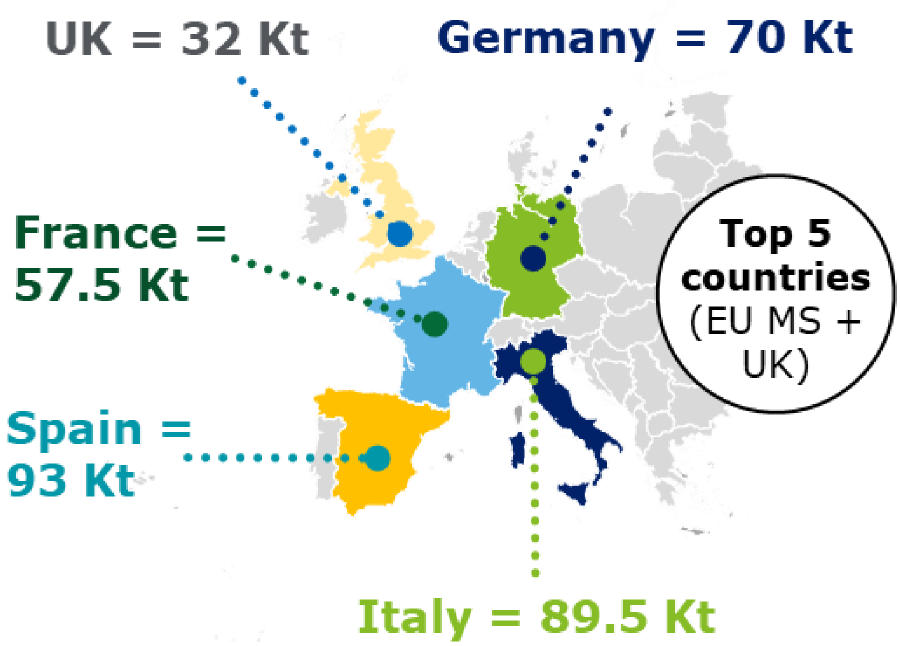
In regard to **geographic distribution**, the different types of agri-plastic applications used across Europe can be directly linked to associated crops and cultures produced across Member States, which is dependent on topographical factors such as climate and the characteristics of available agricultural land. In southern Europe, the main agri-plastic applications are **films for crop production**, while in northern Europe, which is characterised by vast areas of grass land**, silage and stretch films** are largely used for

[19] SEPA website: "Burning on-farm waste". Accessible at: www.sepa.org.uk/regulations/waste/agricultural-waste/burning-on-farm-waste/#transition
[20] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics
[21] APE Europe (2020 Draft) The European Plasticulture Strategy : A contribution to an European agri-plastics waste management

livestock farming e.g. production of animal fodder.[22]

Figure 2-1 shows the **top five countries** (France, Spain, Germany, Italy and UK)) with the highest volume of **agricultural film sales** in 2018. Together these countries accounted for approximately 342 kt tonnes or 64% of the total volume of agricultural film sales reported in 2018 (see also Figure A2.7 in the Appendix). Spain and Italy represent a particularly significant share of the **agricultural film market**. This is primarily driven by intensive horticultural production activity where large quantities of greenhouse coverings, medium/low tunnel and mulching films are used for protecting cultivations.

Figure 2-1: Top 5 countries: agricultural films sales, 2018 (kt)

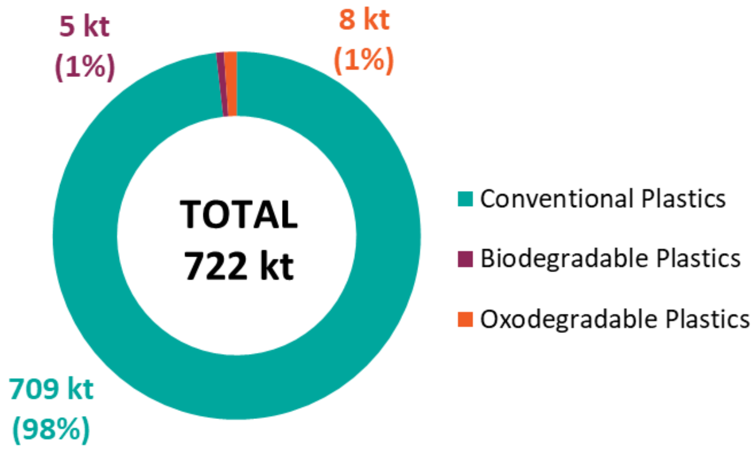


Source: APE Europe

In regard to the use of conventional versus biodegradable plastics, most of the agri-plastic applications placed on the European market are made from conventional plastics (98%) (Figure 2-2). A very small share of biodegradable plastics (5 kt) and oxo-degradable plastics (8 kt) are also used although oxo-degradable plastics are expected to disappear from the European market as of 3 July 2021 following the implementation of the SUP Directive. As such, consumption forecasts for this category are likely to be much smaller than the reported figures. Further, in regard to the volume reported for biodegradable plastics, it should be noted that this only refers to **mulch films**. A very small amount of biodegradable material is reportedly also used for twine, however the market size is uncertain due to its relative infancy.

[22] Scarascia (2012) "Plastic materials in European agriculture: Actual use and perspectives"

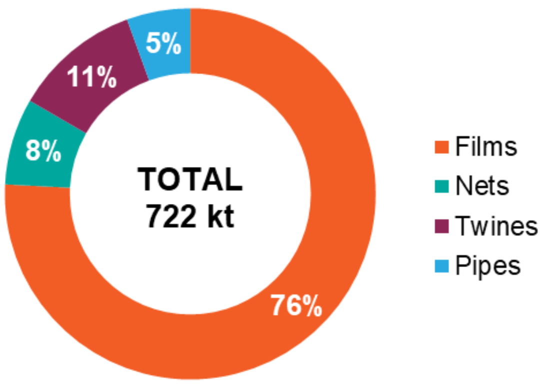
Figure 2-2: Quantity and share of different types of plastics used in agricultural applications (t) in EU, 2019



Source: Data from APE Europe

In regard to agri-plastic applications, in 2019, films accounted for the largest share in Europe, representing approximately 76% of total agri-plastics placed on the market. The remaining market segments included twine (11%), nets (8%), and pipes (5%) (Figure 2-3).

Figure 2-3: Share of main agri-plastic applications placed on EU market, 2019

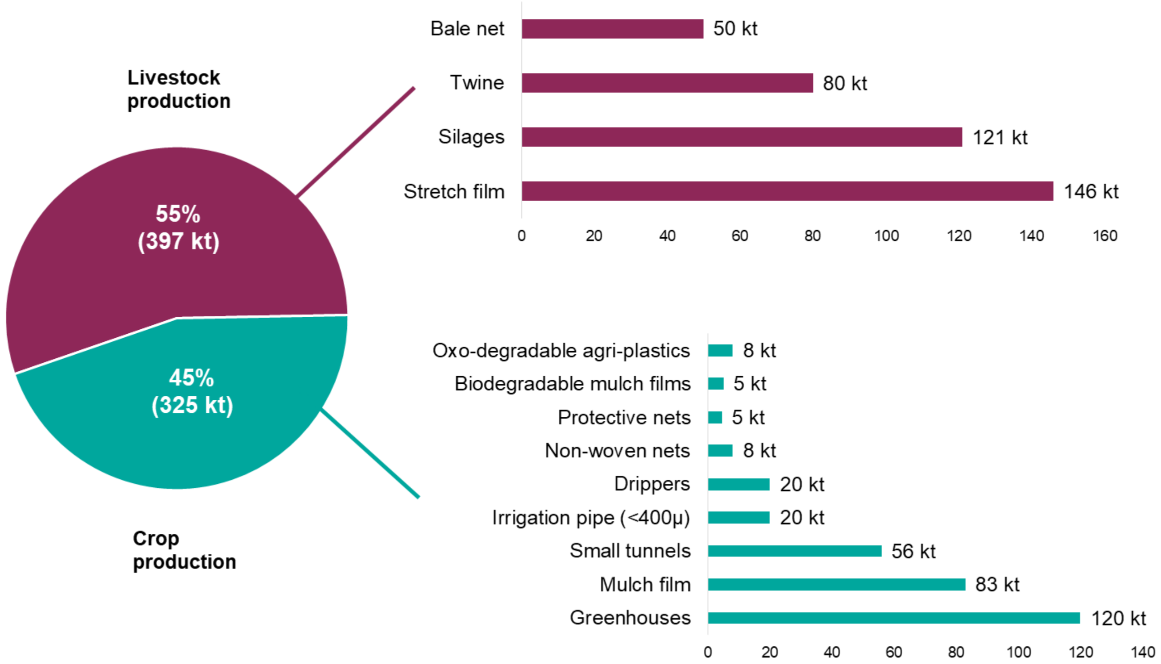


Source: Data from APE Europe

Further segmentation indicates that the principal applications among agricultural plastics are stretch and silage films used to preserve and store feed for livestock, greenhouse films and mulch films for vegetable production. These four applications account for more than 65% of the European agri-plastics market (Figure 2-4).

Except for silages and small tunnels, each of which has increased by 17% in four years, a low-level increasing trend in consumption of other agri-plastic applications has been recorded in the previous years. Mulch films, which are one of the most widely-used applications observed a slight increase of 4% between 2015 and 2019 in Europe.

Figure 2-4: Consumption of agri-plastic applications, by market segment in the EU, 2019.



Source: Data from APE Europe

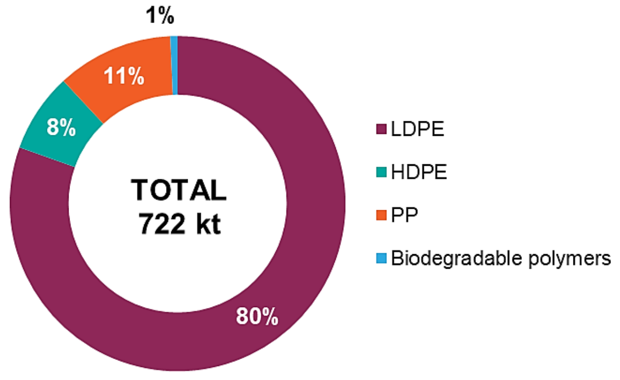
2.5.1.1 Consumption of agri-plastic polymers

In Europe, the market is characterised by high homogeneity in the polymers used for conventional agri-plastics, almost exclusively high and low density polyethylene (HDPE, LDPE) and polypropylene (PP). This homogeneity favours selective collection of agri-plastic waste (APW) and their recycling.

Figure 2-5 provides an overview of the main polymers used in agri-plastic applications in the EU in 2019. LDPE is mainly used to produce agricultural films and pipes[23] and is also the most widely used material, accounting for 80% (574,000 tonnes) of the market in 2019. HDPE is used for netting and accounts for around 8% of the market share, while PP used to produce twines accounts for 11%.

In addition, biodegradable

Figure 2-5: Share of polymers used in agri-plastic applications in EU, 2019



Source: Data from APE Europe

[23] Some pipes are made of linear low density polyethylene (LLDPE) but categorised under LDPE products.

polymers represent 1% of total market share. The polymer types for this product category are not reported at EU level, but according to European Bioplastics the majority of biodegradable products used for agricultural purposes are made from starch blends, PLA and PBAT.[24] Biodegradable materials are increasingly gaining market share in the agricultural film sector, as they are often considered to be a solution for conventional plastics that cannot be collected and enter/accumulate in soil and other environmental compartments. The increase in these materials' production capacity and consumption (+ 67% between 2015 and 2019) in the last years is mainly based on the expansion of poly butylene adipate-co- terephthalate (PBAT) in Europe.

2.5.2 Key Market trends

Overall, the European agri-plastics market is estimated to grow with an estimated average annual rate of 5% (which varies depending on the application and region).[25] The main market segment which has experienced particularly steady growth over the past decade is **agricultural films**. Soil protection to avoid weed growth, reduce water evaporation, increasing cost efficiency as well as the rising standards of global farming are major drivers for the use of these products. The market for agricultural films is expected to continue growing over the next years with the rising demand for food along with increased agricultural productivity. Although the population increase in Europe is expected to be only marginal, European agriculture will continue to play its part in global food production.

Films manufactured with linear low-density polyethylene (LLDPE) are anticipated to lead the global **agricultural films market**, owing to advanced properties such as mechanical strength, moisture barriers, optical properties, and resistance to sunlight. In addition, the various innovations in the sector targeting the development of new plastic additives namely fluorescent, UV, NIR blocking, screens and ultra-thermic screens will also drive the agricultural films segment. These chemicals improve the film integrity during its entire service life by reducing the effects of cumulative UV radiation and other external and environmental factors. Companies are also increasingly developing high performance thinner multilayer films composed of different polymers. However, these products cannot currently be recycled using traditional plastic recycling technologies (e.g. mechanical recycling) owing to the chemical incompatibility of the different layers.[26] Their recyclate would be composed of heterogeneous materials, making them more difficult to use for manufacturing of new products. Therefore, despite the few advantages of this category of product (e.g. for greenhouse application), it is

---

[24] European Bioplastics (n. d.), Bioplastics market data. Retrieved from: www.european-bioplastics.org/market/

[25] BASF (n.d.). Plastic additives for agricultural plastics. Accessible at: https://agriculture.basf.com/global/en/business-areas/crop-protection-and-seeds/use-areas/agricultural-films.htm

[26] Walker, T. W., Frelka, N., Shen, Z., Chew, A. K., Banick, J., Grey, S., ... & Huber, G. W. (2020). Recycling of multilayer plastic packaging materials by solvent-targeted recovery and precipitation. Science advances, 6(47), eaba7599.

recommended to avoid its development and use in the absence of adequate recycling infrastructure.

In terms of applications, a report from Applied Market Information Consulting predicts that the consumption of silage film will grow by 1% per year, led primarily by booming biomass production as well as rising demand for higher quality fodder and silage (also being increasingly fed to horses) and the increased wrapping of hay bales.[27] Demand for greenhouse films is expected to decrease in the coming years, according to Plasteurope. The market for greenhouse films is a mature one, with one-season films gradually being replaced by films made to last for longer periods e.g. up to five years. It should be noted that although these market estimations were made five years ago by AMI consulting, according to APE Europe, the market projections still remain relevant and valid.

For conventional mulch film, Plasteurope reported that consumption is expected to decline slightly over the next years as a result of the relative maturity of the market, combined with a decrease in available agricultural land for crop cultivation and the need to reduce the quantity of post-use plastic waste by down gauging or using biodegradable films instead. However, accurate growth projections are somewhat difficult to achieve for bio-based and biodegradable products in general and are typically overstated due to an expectation that these products will gain in popularity. Lower than expected investment in production capacity and the relative cost compared with conventional fossil-based incumbents have ultimately suppressed a lot of this expected growth. One market research report suggests that global biodegradable mulch film market will see a compound annual growth rate (CAGR) of 9.3% from 2017 to 2023[28] However, this is a considerably larger growth rate than is predicted for the whole *bio-based* industry of 3% CAGR[29] and demonstrates the lack of consensus around market growth in this sector. According to APE Europe, biodegradable mulch films are unlikely to entirely replace conventional ones, which are estimated to peak at a market share of 10-15%. There appears to be no particular market driver for biodegradable mulch films to reach this level in the near future.

2.5.3 Agri-plastic waste generation

The increase in plastics consumption in the European agricultural sector in recent years has resulted in the generation of large quantities of agri-plastic waste (APW). According to APE Europe, in 2019, the EU agricultural sector generated approximately 1.18 million tonnes of post-consumer non-packaging plastic waste. Note that this figure includes contamination (e.g. soil, mineral, water and organic materials) and therefore is

[27] Applied Market Information Consulting (n.d.). Agricultural films. Available at: www.plasteurope.com/news/AGRICULTURAL_FILMS_t228787

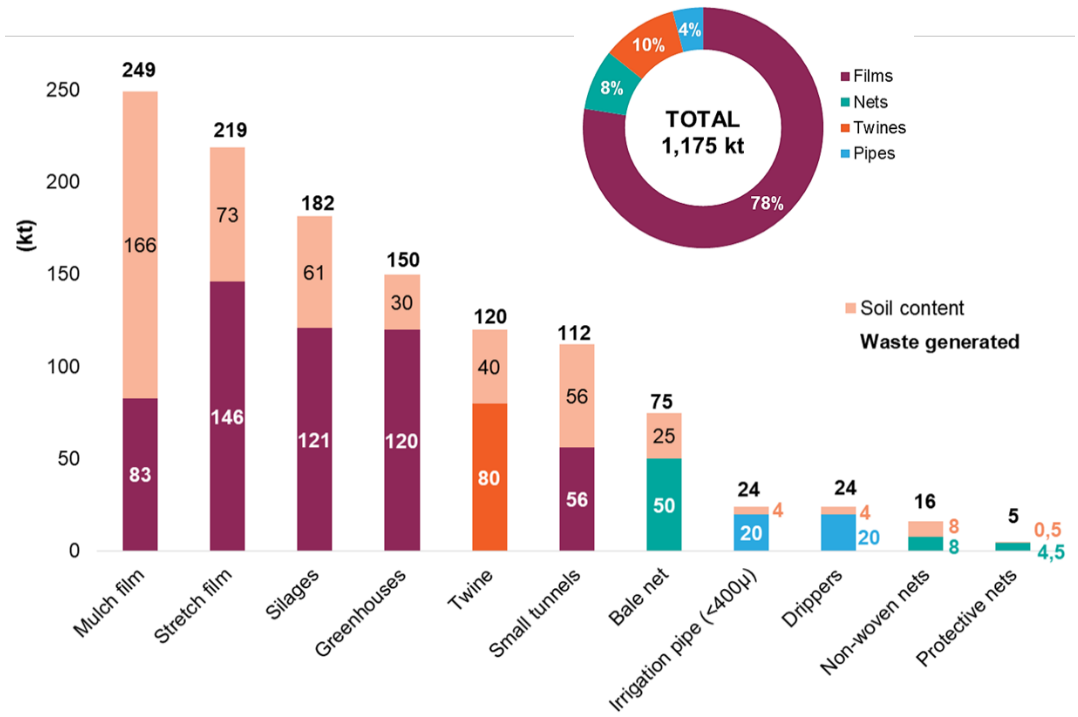
[28] Allied Market Research (2017). Global biodegradable Mulch Film Market - Global Opportunity Analysis and Industry Forecast, 2017-2023. Available at: https://www.alliedmarketresearch.com/biodegradable-mulch-film-market

[29] Michael Carus, nova-Institute (2019). Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2019 – 2024.

considerably larger than annual consumption. The sector represents a small fraction of the total plastic waste generated in Europe, accounting for just 5% of all plastic waste generated within EU-28 plus Norway and Switzerland.[30]

As illustrated in Figure 2-6, the main agri-plastic waste streams generated within Europe are agricultural films, in particular stretch films, silages and greenhouses, which are also the principal types of agri-plastic applications used in Europe. Further, mulch films have the highest contamination rate.

Figure 2-6: Quantity (kt) and share (%) of APW generated in EU, 2019 (including soil contamination)



Source: Data from APE Europe

2.5.4 End-of-life practices

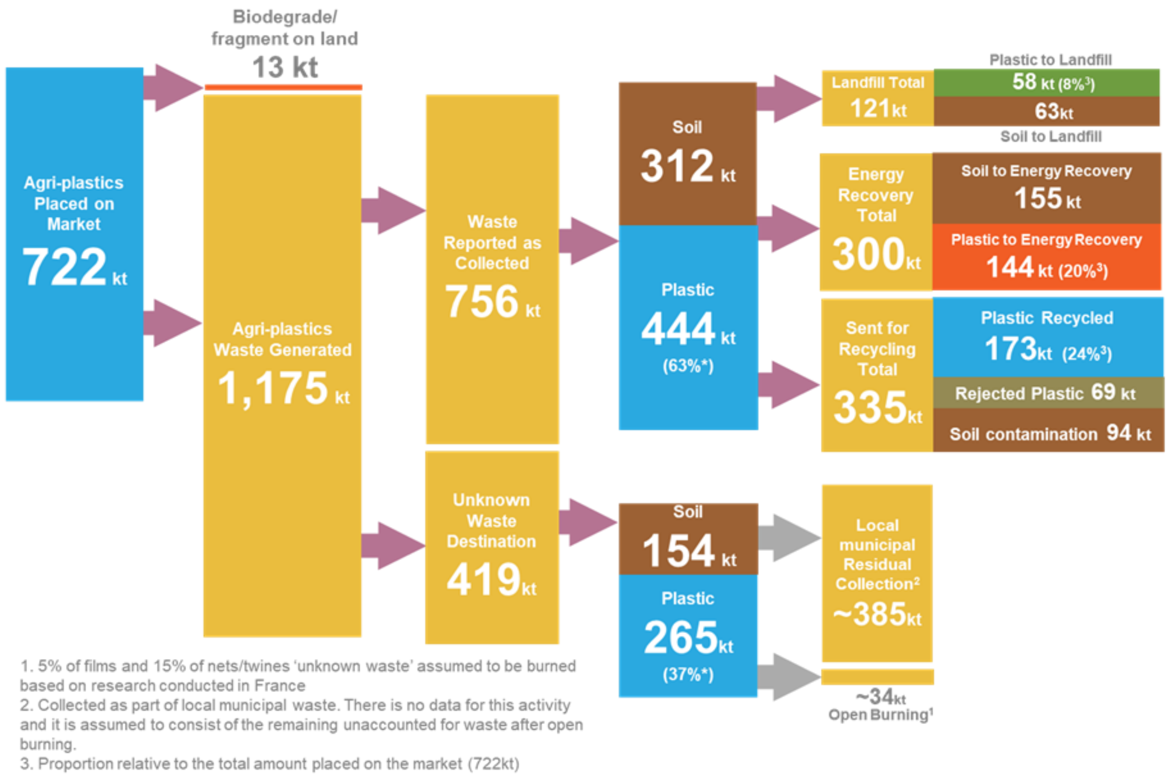
At end of life, agri-plastic waste is managed in Europe via different treatment or disposal methods, which can depend on aspects such as the quality and characteristics of the waste and national specificities e.g. specific national legislation, waste management infrastructure, existence of a dedicated collection scheme, etc. In countries with an established collection scheme, waste streams with relatively low contamination e.g. greenhouses, silages or stretch films are collected and sent for recycling, while highly contaminated waste streams e.g. mulch films are most likely landfilled or incinerated for energy recovery. Where effective collection schemes do not exist, farmers may be more

[30] PlasticsEurope (2019). The Circular Economy for Plastics – A European Overview. Available at: www.plasticseurope.org/en/resources/publications/1899-circular-economy-plastics-european-overview

inclined to burn or bury the waste on site. Each of these EOL practices is further detailed in the following section.

The most recent figures obtained on EOL practices for agri-plastic waste at EU level are summarised in Figure 2-7. The figures presented are based on data provided by the AGRI Working Group within the Circular Plastics Alliance (CPA) and APE Europe. To ensure overall consistency and robustness of the data provided by APE Europe, reported figures have been cross-checked with those reported by PlasticsEurope. It should be noted that there is no indicator for APW re-use in Europe. ADIVALOR estimate around 5% of uncollected waste is burned onsite (see Section 2.5.4.5), but the remaining 'unknown' waste may also be collected primarily in local municipal services, but this is unrecorded and uncertain. Whilst no data for residual treatment was available for 2019, later 2020 figures provided by APE show a split of 29% landfill and 71% incineration (see Section 2.5.4.4). Finally, recycling figures vary, but those reported by PRE appear to incorporate the most realistic estimates for losses and are therefore taken forward to estimate 24% recycling rate overall (See Section 2.5.4.3).

Figure 2-7: 2019 Agri-plastic Waste Generation and End of Life

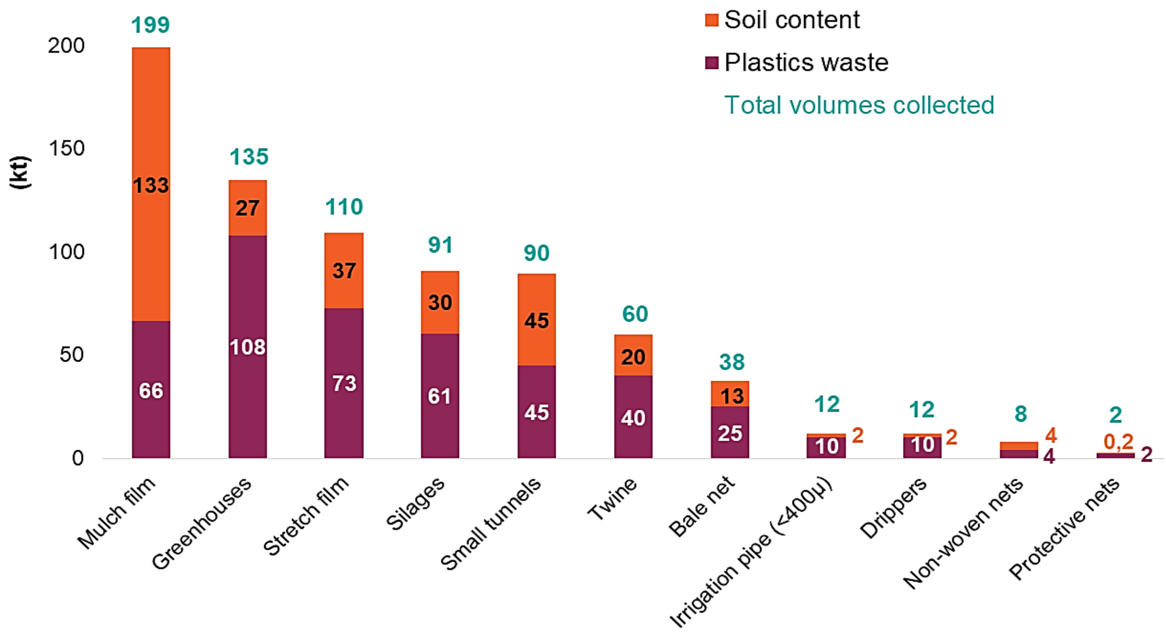


2.5.4.1 Collection

There is no established EU-wide collection scheme targeted specifically at non-packaging agri-plastic waste. However, several collection schemes exist in certain Member States and are further discussed in Section 2.6.

According to APE Europe, approximately 64% of non-packaging agricultural plastic waste generated in Europe was collected in 2019, representing a total volume of 756 kt.[31] This volume takes into account contamination, which accounts for an average share of 41% of collected waste. The contamination level depends on the type of application as indicated in Figure 2-8, and can be significant for some products – e.g. exceeding 67% for mulch films. Levels of contamination are also dependent on the care taken during use, removal practices and storage conditions of plastic waste in fields. The average collection rate of non-packaging agri-plastics is thus estimated to be 38% excluding contamination. The main applications which are largely collected are greenhouses, silages and stretch films due to their lower contamination level.

Figure 2-8: Volume of agri-plastic waste (excl. packaging) collected in the EU and share of soil content by application (kt), 2019



Source: Data from APE Europe

The collection rate also varies from country to country. Countries with a well-established national collection scheme such as Ireland, Iceland, Norway, Sweden, France, and Spain have achieved a high collection rate reaching more than 70%. The other European countries have no identified national collection scheme, but waste collection may occur locally or regionally and organised by individual contracts with farmers and growers or by public authorities. In those countries, the collection rate is much lower and inappropriate practices or landfilling are largely applied (APE Europe, 2019).

[31] Pesticide and fertiliser bags and containers waste are considered as packaging waste and regulated under the Directive 94/62/EC on Packaging and Packaging Waste

2.5.4.2 Re-use

There is currently no official indicator that monitors agri-plastics re-use in Europe. Likewise, no definition for "re-use" specific to agri-plastics is established at EU level. Due to the important challenge of ensuring full traceability, it is not clear to what extent agri-plastics are being re-used for the same original purpose and/or for completely different purposes. The re-usability of agri-plastics is highly dependent on both local farm conditions e.g. care taken during practical use of the product and regional contexts e.g. geographic and climate conditions. As such, it is difficult to quantify the exact amount of agri-plastics that are re-used within Europe. Nonetheless, it is estimated that overall, a relatively low amount of agri-plastics are re-used in Europe.[32] Many agri-plastic applications are characterised by a fairly short life span, in particular films. The majority of agricultural plastic films currently in use are affected by a progressive deterioration of their mechanical and spectro-radiometric properties based on thickness, exposure to solar radiation and pesticides, variations in temperature, levels of humidity, wind and rainfall, and type of installation (Picuno, 2014).[33]

Products that are re-used are generally characterised by high thickness, low levels of contamination and less exposure to environmental changes. However, as stated above, it is not clear how and to what extent such products are being re-used i.e. left in situ over multiple cycles for the same original purpose or re-used for completely different purposes. For example, in Spain and Italy, the re-use of conventional agri-plastics mainly involves greenhouses and in some rare cases mulch films. Depending on conditions of use, topographical and climatic aspects, etc., greenhouses can be used for multiple cycles; up to 3 and 4 years (compared to single cycle of 1 to 2 years). When in sequence crops are involved in the same year, conventional mulching films is re-used in some rare cases for 2 or 3 different types of crops e.g. films used for lettuce can also be re-used for squash. In addition, in some cases, due to their thickness, mulch films for asparagus can also be re-used for more than 1 cycle. In France, it is estimated that 10-15% of silage films and twines are currently reused.[34]

Other agri-plastic applications, which can be used several times without affecting their overall performance and function include stretch films, tubes and sheets. These products can be re-used for a range of different purposes, for example to cover piles of wood and hay, machinery as well as to serve as protective liners for horizontal silos.

2.5.4.3 Recycling

According to APE Europe, the volume of APW recycled in the EU reached almost 335 kt in 2019 which equates to a 47% recycling rate. Greenhouse, stretch, and silage films are the main products that are recycled due to their relatively low contamination level.

---

[32] APE Europe (2020) *Plastics Data*

[33] 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.

[34] Interview with ADIVALOR

However, this data is based on a blanket assumption that after soil is removed, the plastic is subject to only 5% losses during recycling (the exception being 100% losses for mulch films and bail nets) with an average yield from recycling of 64% including soil.

In order to validate this data, Plastics Recyclers Europe (PRE) also provided figures for recycling which suggested that only greenhouse, silage and stretch films are collected for recycling at present (i.e. no other nets or twines or mulch films). Yields of 30-70% were reported with an average of 56% which is lower than reported by APE. The yields reported by PRE are also in line with those reported by recyclers in Section 3.2.3 and result in plastic losses of 13-55% which is more realistic than 5% particularly for highly contaminated material. For this reason, these loss rates are applied to the collection figures from APE to provide a more conservative estimate for **total plastics actually recycled of 173 kt** (335 kt sent for recycling with 94 kt of soil contamination and 69kt of rejected plastic). This is the figure taken forward in the baseline in Section 5.0 and represents a recycling rate of agri-plastics placed on the market of 24% which is considered a more realistic estimate than 47% from the APE figures. The disparity in these figures, does further highlight the need for more unified reporting across the EU that relies less on assumptions.

Each agri-plastic application demonstrates different behaviour in its end-of-life and therefore will have to follow a specific route before being eligible for recycling. The potential for recycling mainly depends on the cost-effectiveness of the process which takes into account the level of contamination. Waste streams having a high contamination level lead to significant additional costs in terms of recovery operations and treatment, and vice versa:

- **Greenhouse films** which are thick, transparent, and have generally a small soil content, are easy to clean and largely sent for recycling. They are appreciated by recyclers and therefore their value is still positive on the market. In consequence the collection and recycling rates are relatively high. This also applies for silage films, as well as stretch films, twines and irrigation pipes but the plastic proportions recycled are very different. For example, more than 68% of greenhouse films generated are recycled, while 40% of pipes are recycled; [35]
- **Small tunnels films** are thinner and translucent, with a soil content of medium range. These films are also sent for recycling when collected appropriately but may end up in landfill and in some cases buried onsite. 38% of small tunnels waste generated are recycled;
- **Mulch films,** which are mainly black, present a lower thickness compared to the other applications, and have a very high soil content (3 to 5 times the weight of plastic).
- **Bale nets** are also one of the most challenging waste streams today in terms of management, according to APE Europe. With no possibility of reuse or to be

[35] APE Europe (2020) *Plastics Data*

recycled (no facilities in Europe), collected nets are 100% sent to landfill or burned/ buried.

2.5.4.4 Energy recovery and municipal landfilling

Energy recovery and municipal landfilling are used typically to dispose of agri-plastic waste that cannot be sustainably recycled. These mainly include agricultural films, which have been exposed to heat, pesticides, dirt, grease, and rodents, rendering them too contaminated to be re-used or recycled, and bale nets for which there are no existing recycling facilities due to the contamination (further detailed in Section 3.2).

According to APE, of the collected material not sent for recycling, 71% is sent for incineration and 29% to landfill. The 'unknown' fraction of the waste generated may also be, in part, collected by municipalities and this is likely to be sent for residual treatment although the exact destination in not known.

Most of the APW management operators are mobilising to reduce the share of municipal landfilling due to the potential risk that this practice can pose on human health, animals and the environmental issues it may cause such as ground water contamination (production of leachate which contaminates the soil and the ground water), and sanitary related issues, etc.[36]

2.5.4.5 Illegal burning (on site)/ burial in soil

There are no official available data at EU level regarding burning or burying agri-plastics waste on site due to the absence of a specific EU wide regulatory framework. Despite the existence of national measures prohibiting the open burning of agricultural waste (see Table 2-3), this practice is thought to still be applied in some Member States. For example, in Spain, ASAJA indicates that some burning and burial of waste is taking place in fields, or left in surrounding areas.[37] For example, the ASAJA (Spanish Young Farmers Association) estimated that in Spain there are *"around 950,000 ha of agricultural land and the rural environment that are affected by the contamination by agro-plastics out of use and almost half, need immediate intervention."*[38] According to ADIVALOR, in France in 2016, while approximately 95% of **agricultural films** were collected either by the collection scheme (>65%), private companies (5%) or the municipal waste disposal centres (25%), it is estimated that the remaining **5% of agricultural films not collected**

---

[36] Hidayah, N. (2018). A Review on Landfill Management in the Utilization of Plastic Waste as an Alternative Fuel. In E3S Web of Conferences (Vol. 31, p. 05013). EDP Sciences.

[37] Marí et al. (2019) Economic Evaluation of Biodegradable Plastic Films and Paper Mulches Used in Open-Air Grown Pepper (Capsicum annum L.) Crop. Agronomy 2019, 9(1), 36; https://doi.org/10.3390/agronomy9010036

[38] http://www.innovationatiris.com/2020/02/21/iris-invites-you-to-the-ap-waste-project-presentation-on-18th-march/

was burned on site.[39] For **net and twines**, it was estimated that about 85% of the waste generated was collected by the collection scheme (62%), private operators (5%) or sent to municipal waste disposal centres (18%), while the remaining **15% not collected was burned on site**. **Extrapolated up to the EU level this would result in 34 kt of open burning** although this is likely to be a conservatively low estimate due to the fact that France has a relatively well-developed collection system — other countries may see varying amounts of burning taking place which will be linked to the availability of collection.

The main reasons that drive farmers to practice burning include the preparation for collection, which is considered to be too time-consuming (about 16 hours per hectare), coupled by the high costs for recycling (up to € 300 per hectare) – particularly in the case of mulch films.[40] These factors were also cited by the French collection scheme ADIVALOR as the main reasons behind the drop in the quantity collected by more than 6,000 tonnes in 2019.[41]

In general, burying is expected to apply to conventional mulching films, especially if they are particularly thin films, which are difficult to remove from the field and have high soil contamination. There is no evidence to suggest that this is taking place deliberately, but as a result of the films breaking up. This issue and the associated accumulation in soil is discussed further in Section 3.4.1.1.

2.5.4.6 Post-consumer resin (PCR) consumption

Recycled agricultural plastics are not generally incorporated back into agri-plastics products with strict colour or other technical requirements e.g. transparency, elongation, tearing. APE Europe estimates PCR (from agricultural plastics) consumption to approximately 93kt in 2019[42]. The main applications incorporating recycled content from agricultural sector are silages (containing 40% of recycled material), small tunnels, pipes, and twines as indicated in Figure 2-9. According to APE, no recycled agricultural plastic is used for mulch films, greenhouses and nets. **Nevertheless, according to Plastics Recyclers Europe mulch films and greenhouses can incorporate high quality recycled material from other sectors (not specified)**. According to PRE, in 2018, 43kt of recyclates were used in the manufacturing of mulch films (~52% of plastics consumed for mulch films manufacturing) and 6kt for greenhouses.

---

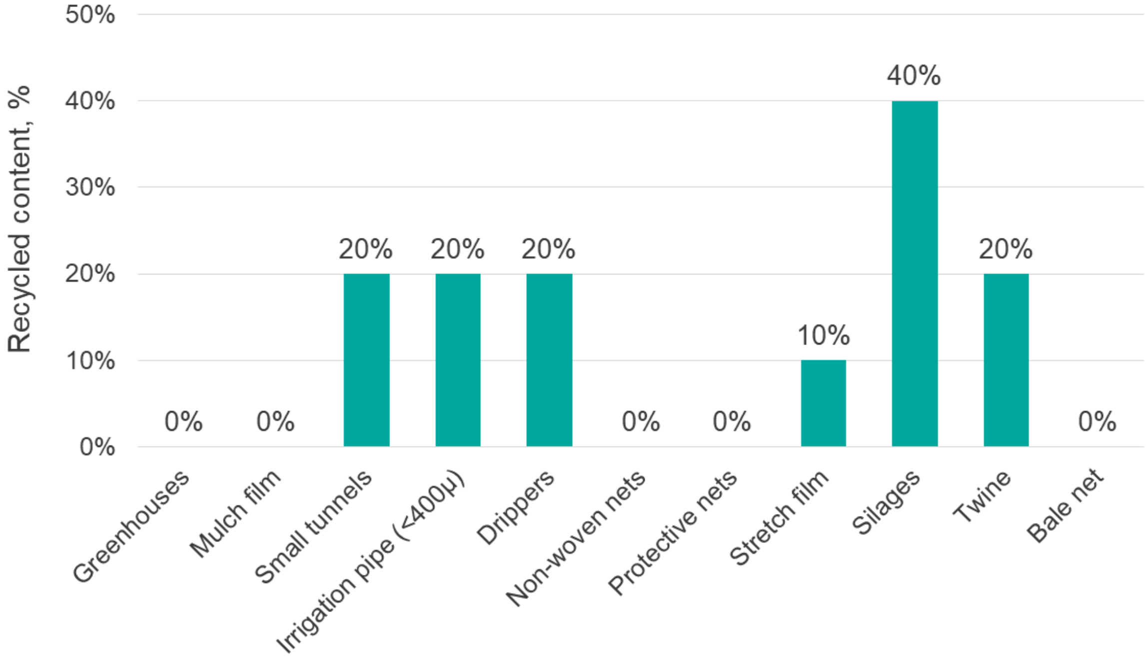
[39] Based on questionnaire responses and interview with ADIVALOR ; and 2016 study conducted by the French Ministry of agriculture on EOL treatment of non-collected APW (both by ADIVALOR and private companies)

[40] OWS. Expert statement : (Bio)degradable mulching films. Retrieved from: https://www.ows.be/wp-content/uploads/2017/08/Expert-statement-mulching-films.pdf

[41] Based on questionnaire responses and interview with ADIVALOR, April 2020.

[42] These estimations have been developed by the AGRI WG within the Circular Plastics Alliance

Figure 2-9: Share (%) of recycled content (from the agricultural sector) per agri-plastic application, 2019



Source: Data from APE Europe

2.6 Agri-plastics Market and EOL Practices at National level

This chapter presents a summary of key trends on agri-plastics consumption, waste generation and end-of-life (EOL) management at national level for a selected number of EU Member States and internationally. The full detailed review of each country assessed is provided in Appendix A.2.2 and where available, data is provided on the following elements:

- Overview of key trends on EOL practices
- Agri-plastics consumption/ placement on the market
- Agri-plastic waste generation and EOL practices
- Market trends and costs

Table 2-4 provides an overview of the existing collection schemes assessed. While some have been established since the mid 1990's, others were only recently launched this year. The collection and recycling rates presented in the table below are based on figures reported directly from the scheme. Overall, collection rates can vary from 40% to 90%. Once collected, recycling rates are reportedly high, but invariably these are difficult to confirm.

Table 2-4: Overview of existing collection schemes for agri-plastic waste

Country	Scheme	Date est.	Type	APW streams collected	Collection rate[1]	Recycling rate[2]
Canada	Clean Farms	2010	Voluntary	Silages (bale wrap and silage films)	-	-
France	ADIVALOR	2009	Voluntary	All agricultural films, twines, nets, and flexible irrigation pipes	67% (2019)	76% (2019)
Germany	ERDE	2013	Voluntary	Silage film wraps and sheets and bale nets	37% (2019)	100% (2019)
Iceland	IRF	2005	Mandatory	Silage films	90% (2020)	-
Ireland	IFFPG	2001	Mandatory	Silage films, netting and twine	79% (2019)	-
Italy	Polieco	2019	Mandatory	Greenhouse and mulching films	-	56%[3] (2013)
Norway	GPN	1997	Voluntary	Agricultural plastics packaging and films	83.5% (2018)	60% (2018)
Spain (Andalusia)	MAPLA	2020	Voluntary	All films	-	-
Sweden	SvepRetur	2001	Voluntary	Silage films, plastic bags and horticultural foil	92.5% (2019)	88% (2019)
UK	APE UK	2020	Voluntary	Films, twines and nets	-	-
	UKFPRS	2020	Voluntary	-	-	-

Notes:

1. *Collection rates for specific targeted APW wastes in the service*
2. *Recycling rates are based on what is collected, not overall rate*
3. *Data for Italy is outdated and likely incomplete – these figures should be regarded with particular caution*

The way collection schemes are managed vary from country to country and also at regional level. Most of the existing collection schemes are voluntary-based, with the exception of IRF in Iceland, IFFPG in Ireland and Polieco in Italy, which are all mandatory.

The scope of the types of APW collected also vary across existing schemes. While some cover both packaging and non-packaging agricultural plastic waste, others collect only specific waste streams e.g. Polieco in Italy collects only discarded PE films. Similarly, collection costs also differ significantly, based on the waste collected, distance between farms and collection/treatment centres, and market value for recycled agri-plastic materials. In some countries, such as in Spain (Andalusia region), the high value of recycled agri-plastic material e.g. greenhouse films (150-200 €/tonne) have encouraged and incentivised increased collection and recycling.

Competition between existing schemes is also observed in Italy and the UK. This may affect the overall quantity of waste collected and reduce the clarity to farmers as to the available services. The highly fragmented collection market in the UK for example, has resulted in administrative and logistical burdens for recyclers looking to source plastic for recycling where two schemes have been set up in 2020 simultaneously. The UKFPRS scheme was set up by existing collectors in response to the APE UK scheme that was set up by producers. The collectors objected to a levy being proposed by APE UK that would only be applicable to the 80% of producers who have signed up and there is a perceived threat to their operation. It is unclear how these two competing schemes will interact or affect collection rates in future. This runs in contrary to the German scheme that has existing collectors at its heart and allows them to set their own collection prices. France has also focused on cooperation between producers, farmers and collectors – it appears to be an important factor for the success of *voluntary schemes* that value chain cooperation is achieved. Indeed, even in the mandatory Irish scheme, which has relatively high collections rates, there is no requirement for the farmer to use the scheme—only that producers financially contribute.

Improvements in existing collection schemes are needed to further increase collection and recycling. For example, ensuring the availability of collection services and infrastructure can be challenging, particularly for countries such as Spain, where there is a large variety in the different types of APW generated. This results in collection practices within the country or region, which are not always homogeneous. Waste managers are often more interested in greenhouse and silage films due to higher recycling value and potential, which are mainly located in southern Spain. Consequently, while in the south of Spain there are several waste managers able to collect APW, this is not the case for the North of Spain. In Finland, due to the long distances between farms and collection sites and treatment centres, efficient and available collection services are not always easily accessible for farmers. This was identified as a key area where further efforts are needed in order to increase collection and recycling.

2.7 Summary of Agri-Plastic Consumption and End of Life Practices

The type and quantity of agri-plastic applications used, the amount of APW generated and how it is treated at EOL vary widely across the countries assessed. This is partly due to geographic and market factors in regard to the types of crops and livestock produced, but also due to data limitations.

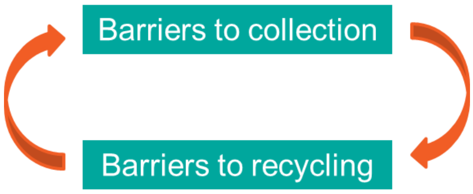
Despite agricultural plastics having a high potential for recycling, according to APE Europe, only 28% of the non-packaging APW generated are currently recycled in the EU, while 42% of the generated APW are disposed of at landfill sites and the remaining 30% sent to energy recovery. Yet, this waste stream has high potential for recycling due to it being produced in large quantities and composed of relatively homogeneous material. In addition, the use of these products is generally concentrated in particular areas of intensive cultivations within a country (farmland mainly in rural areas) which facilitates their collection reaching up to 70% for countries having a collection scheme. In general, within a specific rural region of the country the same cultivations take place using similar agri-plastic applications which are then removed at the same period of the year by farmers. As a result, most of the APW generated at a regional level is rather homogeneous, concentrated geographically and is generated at specific time periods each year.

The lack of available, reliable and recent data makes it is challenging to draw robust quantitative conclusions. Reported data (when available) is not consistent in terms of the scope of applications, years covered, etc. Nonetheless, among the eleven EU countries assessed six have implemented collection schemes for EOL management of agri-plastic waste at regional or national levels.[43] For these countries, data is more readily available on EOL practices, providing good insights on how agri-plastic waste is being managed, although the data is still somewhat difficult to compare in most cases. For countries that do not have established collection schemes,[44] available data is very limited due to the absence of an organisation responsible for collecting data on end-of-life management. As such, quantities of agri-plastic waste generation and EOL practices can only be roughly estimated based on assumptions and what little data is available.

[43] France, Germany, Ireland, Italy, Spain and Sweden.
[44] Poland, Netherlands, Bulgaria, Finland and Greece.

3.0 Aspects of End-of-life of Conventional Agri-plastics

This section of the report explores the challenges related to managing conventional agri-plastics at their end-of-life (EOL). It focuses on two inter-related issues: barriers to the separate collection of agri-plastic waste and barriers to its recycling. There is some overlap between these issues, as the barriers to recycling agri-plastics also weaken the drivers for their collection.



The section is structured as follows:

- **Barriers to the collection of conventional agri-plastics (Section 3.1):**
  - **Barriers to the removal of agri-plastics from the field / farmyard (Section 3.1.1):** a consideration of the challenges related to complete removal of mulch films from the soil.
  - **Barriers that prevent farmers accessing a collection scheme (Section 3.1.2)**: an exploration of why free market drivers are not always sufficient to stimulate the collection of agri-plastics. This section then goes on to illustrate how national EPR schemes have enabled the establishment of recycling collection schemes with wide geographic / product type coverage in some member states.
  - **Barriers that reduce participation in collection schemes (Section 3.1.3):** an exploration of why farmers may not participate in established collection schemes.
- **Barriers to the recycling of conventional agri-plastics (Section 3.2).**
  - **Design of plastics (Section 3.2.2):** a consideration of whether the physical or chemical properties of agri-plastics hinders their ability to be recycled.
  - **Profitability of recycling agri-plastics (Section 3.2.3):** an exploration of how the profitability of recycling agri-plastics compares with alternative plastic material. Contamination is the major factor discussed here.
- **Environmental impacts of improper collection / low recycling rates (Section 3.4):** a summary of the scientific literature assessing the environmental impact of plastic residues in soil.

The findings presented draw heavily on expertise provided by interviews with a number of stakeholders involved in the collection, recycling and production of agri-plastics in Europe.

3.1 Collection of Conventional Agricultural Plastics

The 'collection' of agricultural plastics refers to the stages from removal from the farm to acceptance at a recycler. In theory, the use patterns of agricultural plastics should facilitate collection – large quantities of homogenous material are concentrated in agricultural regions and removed from the field / farmyard often at similar times of the year (e.g. silage wrap is used over the dry / winter season). However, as outlined in Section 2.5.4, collection rates vary significantly across Europe, by country and product type. The barriers to the collection of agri-plastics for recycling are explored in turn in the following section.

3.1.1 Removal from the Field

Removal, aggregation, and storage of agricultural plastics at the farmyard / field level is the first stage in any successful collection scheme (whether it be for recycling or otherwise). For most agricultural plastics, removal from the field has not been highlighted as a significant issue for farmers. The exception to this is mulch films. The process of recovering mulch films is time (up to 16 hours/ha) and labour intensive, and made more difficult by the fact that a large percentage of the weight of the mulching film is soil with organic matter.[45,46] Though there is no evidence of conventional mulch films being directly ploughed into the soil in the first instance in Europe (as is sometimes practiced in China), anecdotal evidence suggests that often some mulch film remains in or on the soil after attempted removal (i.e. due to tearing). For example, in Spain, stakeholders have observed thin plastic mulch (~15µm) accumulating in soil, to the point where some types of crops, such as cereals from the seed, are not viable.[47]

The very limited information that exists indicates that there is a relationship between mulch film thickness and the quantity of film left in or on the soil after removal. APE estimates that 10% (by mass) remains in or on the soil for 25µm film, 25% for 20µm film and 68% for 10µm film; although the original source / study that produced this data has not been confirmed by APE and these figures appear to persist throughout the evidence submitted by stakeholders (occasionally attributed to OWS) with no confirmed basis.[48] **These estimates are therefore considered to be expert opinion rather than based on collected data and are treated with caution, as such.**

The European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) specifies that for black mulch films the minimum thickness should be 20 - 25µm. However, the standard is not mandatory; the

---

45 Briassoulis, D., Babou, E., Hiskakis, M., and Kyrikou, I. (2015) Analysis of long-term degradation behaviour of polyethylene mulching films with pro-oxidants under real cultivation and soil burial conditions, *Environmental Science and Pollution Research*, Vol.22, No.4, pp.2584–2598

46 OWS (2017) *Expert Statement - (Bio)degradable Mulching Films*, accessed 24 June 2020, https://docs.european-bioplastics.org/publications/OWS_Expert_statement_mulching_films.pdf

47 Communication from Asobiocom, September 2020

48 APE Europe (Agriculture Plastic Environment), Industry association for the non-packaging agri-plastics presentation by Bernard Le Moine at Agricultural Film 2014, as cited in Accumulation of (bio)degradable plastics in soil, paper given at CIPA Congress, 2018, Arcachon, http://cipa-plasticulture.com/wp-content/uploads/2018/06/Deconinck-Arcachon-May-2018.pdf

proportion of mulch film products that comply with the standard is not known, although it is understood that the thinnest films possible (~10 µm) are marketed as a 'cost saving', albeit this may prove to be a false economy in the longer term if this leads to higher rates of accumulation of film in the soil, which may increase the risk that yields are negatively affected.

Further afield, a study from China found 15% of the cumulative mulch film used on a field remained in the soil during sampling.[49] However, this appeared to vary between crops, with cotton and maize responsible for the highest remaining residues of 17% and 13%, respectively. Vegetable crops had an average of 9% remaining. Given that the films in use in China are around 6-8 µm thick (and therefore are more likely to leave residue compared with thicknesses typically used in Europe), the APE European estimates would appear to be somewhat overestimated in comparison. The Chinese study provides the only confirmed data on the relationship between mulch film application and residues in the soil. The lack of empirical data from Europe is a considerable gap in existing knowledge, particularly considering that the Chinese data points show crop type has a large effect on film residues in the soil.

This particular aspect agrees with anecdotal evidence from Europe that suggests for certain crop types, such as pineapples, removal of mulch films from the soil is particularly difficult and up to 20% of material may be left in the soil.[50] **The implication of this is that it is not currently possible to achieve a 100% removal rate of mulching films for certain crop types.** The potential environmental impacts of plastic residues accumulating and remaining in the soil are discussed in more detail in Section 3.4.

3.1.2 Access to a collection service

Once agri-plastic material has been successfully removed from the field or farm after use, the collection rate depends on the following factors:

- Farmers being able to access a collection service (by type of polymer, to facilitate recycling);
- Farmer participation in the collection service.

Free market drivers

The ability of farmers to access a collection service for agri-plastic material varies across Europe. In some member states the collection of agri-plastics is left entirely to the free market, whilst in others there are more formalised national collection schemes (NCS). In member states without a NCS, a private sector collection for agri-plastics will only exist where there are sufficient economic drivers in place. In many regions such economic drivers do not exist (particularly for a *recycling* collection service), because recyclers

[49] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., and Wang, H. (2016) The status and distribution characteristics of residual mulching film in Xinjiang, China, *Journal of Integrative Agriculture*, Vol.15, No.11, pp.2639–2646

[50] Interview with APE Europe

either charge high gate fees for most types of agri-plastic waste or do not accept it. The drivers behind this are mentioned below, but discussed in more detail in Section 3.2.3.

Many types of agri-plastics are not profitable to recycle, largely due to high contamination levels and limited end-markets for recyclate.[51] The costs associated with recycling these plastics tend to outweigh the value of the recyclate produced (though thick, transparent greenhouse film is an exception).[52] Alternative, cleaner plastic feedstock—for example, post-consumer and post-industrial films— is more attractive to recyclers. As a result, recycler demand for agri-plastics is low, and the recyclers that *do* accept agri-plastics are forced to charge high gate fees to make it economically viable. This situation has been exacerbated in recent years with the Chinese ban on importing plastic waste: higher quality packaging plastics that used to be exported to China are now flooding the European market. The result of this is that recyclers who used to accept contaminated agri-plastic material have switched to more profitable alternatives.[53]

High contamination rates also increase the cost of transporting agri-plastic waste. Mulch films can reach up three times their original weight after use, making the cost of transport per tonne of polymer expensive.[54] Coupled with this, collectors may be forced to transport agri-plastics long distances to reach a recycler willing to accept removed agri-plastics as a feedstock.[55] For example, the French ADIVALOR collection and recycling scheme exports 30% of agricultural films collected to Spain, Poland and the Netherlands, because agricultural film recycling capacities are insufficient in France.[56]

In order to cover their costs (transport and gate fees) and include a profit margin, recycling collectors may be forced to charge prices that are not competitive with alternative EOL management options (i.e. landfill or incineration). In such circumstances, a recycling collector is unlikely to be able to sustain itself. This is evidenced by collectors, such as Birch Farm Plastics in the UK, ceasing to provide services (see case study in Box 3-1).

Box 3-1: Case study - Birch Farm Plastics (UK collector)

Birch Plastics was the only collector of agricultural plastics in Wales, but in 2019 it was forced to suspend its services when the economic situation regarding the recycling of agricultural plastics both in the UK and abroad changed to such an extent that it was difficult to run a viable collection service.

Following the Chinese ban on the import of plastic waste, the European market was flooded with plastic material. Recyclers who had previously accepted agricultural

[51] Interviews with CEDO, APE Europe and Berry BPI
[52] Interview with CEDO
[53] Interview with CEDO and Berry BPI
[54] Data from APE Europe
[55] Interview with ADIVALOR
[56] Data from ADIVALOR

films, instead opted to fill capacity with alternative (more desirable and less contaminated) material, including plastic packaging.

Plastic packaging is particularly desirable to recyclers in the UK because of the Packaging Recovery Note (PRN) system. Under the Producer Responsibility Obligations (Packaging Waste) Regulations 2007, businesses operating in the UK have an obligation to pay a proportion of the cost of the recovery and recycling of their packaging. Accredited recyclers can issue a PRN for every tonne of packaging they recycle, which they can then sell to obligated companies or compliance schemes who use the PRN system to prove their compliance with the regulations. The PRN acts as an additional income stream for UK recyclers who recycle packaging.

With an increase in the availability of alternative plastic feedstock (e.g. packaging), UK recyclers stopped paying collectors a contribution for delivering agricultural plastics, as used to happen, and switched to charging a substantial gate fee (£70+/tonne). In response, agricultural plastic collectors such as Birch Plastics were forced to increase collection charges to cover their costs, to such an extent that they no longer were competitive in comparison to landfill.[57]

In countries where the collection of agri-plastics is left entirely to the free market, recycling collections may exist in some areas – for example, in areas surrounding recycling plants that require feedstock – but will be absent in others. Furthermore, recycling collections may exist for some more desirable materials (e.g. clear greenhouse films), but not others (e.g. mulch films). This is the experience of many growers in Italy (see Box 3-2). This "patchwork" pattern of collection services acts as a barrier to high collection rates.

Box 3-2: Case Study – APW Collection in Italy[58]

In Italy, the experience of growers is that waste managers will collect greenhouse film for low or no cost, but often refuse to collect mulch film (especially if mulch films make up a large proportion of the waste). If mulch films are collected, then a fee of between 10 – 26 cents / kg is applied.

Furthermore, the extent to which agri-plastic waste collection is organised varies significantly across the country. In some regions (e.g. Emilia Romagna) waste collection is well organised (small growers bring their APW to collection centres of the agricultural consortia, then waste managers pick up APW from these centres by appointment. Waste managers may also collect directly from larger farms). In other regions (e.g. centre-southern Italy) the situation is different, with no collection centres in some areas.

[57] *Press Release - Polythene Collections Suspended*, accessed 18 March 2019, http://www.birchfarmplastics.co.uk/press-november-14.php
[58] Italian Growers Webinar run by ENT – 23/04/2020

National EPR schemes

In some member states, the economic barriers to the formation of recycling collection services have been overcome by the establishment of national EPR schemes (summarised in in Section 2.6). The idea behind these schemes is that producers support the EOL management of the agri-plastic products they place on the market. Typically, producers pay an 'eco-fee' per tonne of product placed on the market, which is collected by a central organisation and used to fund the collection and the recycling (or disposal) of the material after use. The formation of such schemes is typically stimulated by one of the following:

- **Legal obligation:** For example, the Farm Plastics Regulations in Ireland place a legal responsibility on producers of farm film products to support recycling, by either offering a deposit-refund scheme, or participating in a government approved farm plastics recycling scheme (IFFPG).
- **Voluntary agreement between producers**: Avidalor in France, ERDE in Germany and SvepRetur in Sweden are based on such an agreement. The voluntary model is typically underpinned by a risk of regulatory action from the government if collection and / or recycling rate targets are not met. ERDE is aiming to increase the collection and recycling rates of silage and stretch films to 50% by 2021 and 65% by 2022,[59] while ADIVALOR aims to collect 75% of used agricultural films and to recycle 99% of the film material which is collected.[60]

Ensuring the service available to all farmers is usually a priority for a NCS. This was a condition from the French Farmers' Association when the ADIVALOR scheme was being set up.[61]

The range of agri-plastic product types collected by EPR schemes varies, but typically includes the major applications relevant to the country in question (e.g. the Irish scheme collects silage wrap and sheeting, but not mulch films, as these are rarely used in the livestock dominated agricultural sector in Ireland). Unlike collection services reliant on free market drivers, EPR schemes are funded in such a way that collections can still be offered for product types for which there is little to no demand from recyclers.

3.1.3 Participation in a collection service

The existence of collection services is not the only pre-requisite for high collection rates; farmer participation in such services is also key. The following section explores various factors that may influence participation rates in collection services.

---

[59] *AGRICULTURAL FILMS RECYCLING: Germany's Erde initiative presents voluntary commitment to 65% recycling rate by 2022 | Plasteurope.com*, accessed 3 May 2020, https://www.plasteurope.com/news/AGRICULTURAL_FILMS_RECYCLING_t242812/
[60] *ADIVALOR - ADIVALOR - Outlook*, accessed 4 May 2020, https://www.ADIVALOR.fr/ADIVALOR/objectifs_2004.html
[61] Interview with ADIVALOR

Cost of the service

Farmers are likely to choose the lowest cost option available when managing their agricultural waste at EOL (where a choice exists). As discussed in Section 3.1.2, this can threaten the existence of recycling collection services in some areas and for some products (especially if the cost of the collection service is not subsidised by producers).

The benefit of an EPR scheme is that producers fund a significant portion of the collection and treatment costs through the eco-fee which is paid when the product is placed on the market. Though some (or all) of this fee may be passed onto the farmer in the product cost, it has already been paid by the time the farmer ultimately decides how to manage the product after use. The French, German and Irish EPR schemes all require farmers to also make a financial contribution at the point of collection. For example:

- **IFFPG (Ireland)**: Farmers are charged €20 per half tonne of silage wrap /sheeting at a bring centre and €45 per half tonne for a farmyard collection.[62] Through this contribution, farmers directly fund ~30% of the scheme.[63]
- **ADIVALOR (France)**: Farmers are charged up to €155 per tonne for mulch film and flat sheets depending on contamination levels. Farmers *receive a payment* of €50 per tonne for clean, thick, transparent greenhouse / large tunnel film. There is no charge for other agri-plastic products. [64]
- **ERDE (Germany):** Farmers are charged collection fees for silage wrap / sheeting. These fees are set independently by accredited collection points and therefore can vary. The scheme pays collection points a subsidy based on the tonnage of plastic collected, and through this mechanism incentivises competitive collection fees.[65]

EPR operators do not view these collection charges as a major barrier to collection rates, as they are still cheaper than alternative (legal) EOL options. For example, landfill gate fees in Ireland are €70 to €80 per half tonne of plastic, far higher than the €20 per half tonne charge applied at bring centres. While in Germany, treating plastic via incineration is an option, it is relatively expensive, and with the producer fee subsidy, ERDE collection points should always be the cheapest option from a farmer's perspective.[66] However, any charge at the point of collection may act as a disincentive for farmers to participate.

Convenience of the scheme

The convenience of a collection service for the farmer depends on the amount of time and effort required to prepare and transfer agri-plastic material to the collector. Most recycling collection schemes will require the farmer to prepare agri-plastics in a certain way, for example, requiring removal of contamination and then rolling / bagging different types of agri-plastics separately (see Appendix A.3.1 for ADIVALOR's preparation instructions as an example). To support this requirement, the collection

[62] *FAQ*, accessed 4 May 2020, https://www.farmplastics.ie/faq/
[63] Interview with IFFPG
[64] Data from ADIVALOR
[65] Interview with RIGK
[66] Interview with RIGK

charge structure often includes a financial incentive for farmers to remove contamination (e.g. a weight-based charge). The stakeholders interviewed did not identify the preparation requirements as particularly onerous, though it was mentioned that the time farmers spend removing contamination is likely to depend on the financial benefit of doing so – those with greater volumes of material to manage are likely to put more effort into decontaminating their agri-plastics when a weight-based collection fee is applied.[67]

The return infrastructure is also a key determinant of how convenient a scheme is. Most EPR schemes run 'return points' or 'bring centres' for a certain number of days per year, at locations that farmers would regularly visit (e.g. retailers, traders, co-operatives, and agricultural fairs). Farmers in France are on average 15 – 20km away from their nearest return point, a distance decided in co-operation with the farmers.[68] Similarly, farmers in Ireland are on average 10km from the nearest bring centre.[69] In some cases, farmers can also opt for an on-site collection, though this is usually reserved for those who can aggregate larger amounts of plastic in volumes of at least a container load. This option may or may not be more expensive, depending on the volume of material the farmer has accumulated and the proximity of the farm to a recycling plant.

In general, the preparation and transfer of agri-plastics to collectors does not appear to be a significant barrier to participation in well-established collection schemes, but it is possible that it may deter a minority of farmers – particularly those who accumulate only small volumes of agri-plastic waste that can be managed via another route (e.g. drip-fed into the household waste stream or burnt on site).

Awareness

In some cases, despite a scheme with a dense collection network and a cost-advantage over other EOL management methods, collection rates are still relatively low. This is the case for the ERDE scheme in Germany, which despite a wide geographic coverage (in 2019 it ran 450 collection points and 1,200 mobile collections), and being the cheapest EOL option available to farmers, is currently achieving ~40% collection rates for silage wrap and sheeting.[70] The scheme operator assumes that the main reason for this is a lack of awareness among farmers about the scheme – some farmers in Germany are still choosing to use private disposal companies at additional cost.[71]

Over time, and with a well-planned, systematic communications plan, it is expected that this barrier can be overcome. ERDE uses distribution supply chains to transmit information to farmers, including dates of collection and terms of acceptance. The scheme is also marketed at large agricultural fairs. Furthermore, ERDE representatives are present at all collection points during the first year of operation, and use this as an

[67] Interview with ADIVALOR
[68] Interview with APE EUROPE
[69] *FAQ*, accessed 4 May 2020, https://www.farmplastics.ie/faq/
[70] Interview with RIGK
[71] Interview with RIGK

opportunity to educate farmers on the recycling process, and the importance of supplying clean plastics.[72]

Cultural factors

Cultural factors and farmer attitudes towards waste management can act as a barrier to participation in collection schemes. For example, despite the ADIVALOR scheme being the same across the whole of France, collection rates are higher in the North compared to the South, where attitudes to waste management are reported to be different.[73]

Quantity of material

Data from established national collection schemes indicates that collection rates vary by agri-plastic product, even when farmers can return them using the same system. For example, under the ADIVALOR scheme, collection rates for nets and twines are between 30% and 40%, compared to collection rates of over 70% for agricultural films and irrigation piping. The scheme operators assume that the key reason for this difference is the quantity of material produced per farm. A farm in France is likely to accumulate <100kg (which would take up the space of a small wheelie bin) of netting and twine per year and it is possible to manage such low volumes of waste via a method outside of the scheme if the farmer so chooses (e.g. via the household waste collection stream or via a municipal waste collection centre).[74] This option is not a possibility for large quantities of bulky agricultural films.

Mismanagement of agri-plastic waste

There is some evidence to suggest that mismanagement of agri-plastic waste is occurring even in countries with an EPR scheme. As an example, the French Ministry of Agriculture conducted a study on the end-of-life of non-collected agri-plastics in 2016, which estimated that 5% of agricultural films, and 15% of netting and twine were burned on farms.75 The exact drivers for this are not clear, but it could be to avoid the weight based collection charges applied to mulch films, or because the low volumes of netting / twine make it easier to burn this material on-site without detection. As these figures represent a country with a reasonably successful national collection scheme, it is likely that these proportions could be much larger in places that do not have access to such a scheme.

Summary for Collection of Conventional Agricultural Plastics

In summary, the main barriers to the collection of agri-plastics for recycling across Europe are:

- **Technical characteristics of mulch films which may mean it is difficult to completely remove the film from the soil without it tearing**;

---

[72] Interview with RIGK
[73] Interview with ADIVALOR
[74] Interview with APE Europe
[75] Based on questionnaire responses and interview with ADIVALOR ; and 2016 study conducted by the French Ministry of agriculture on EOL treatment of non-collected APW (both by ADIVALOR and private companies)

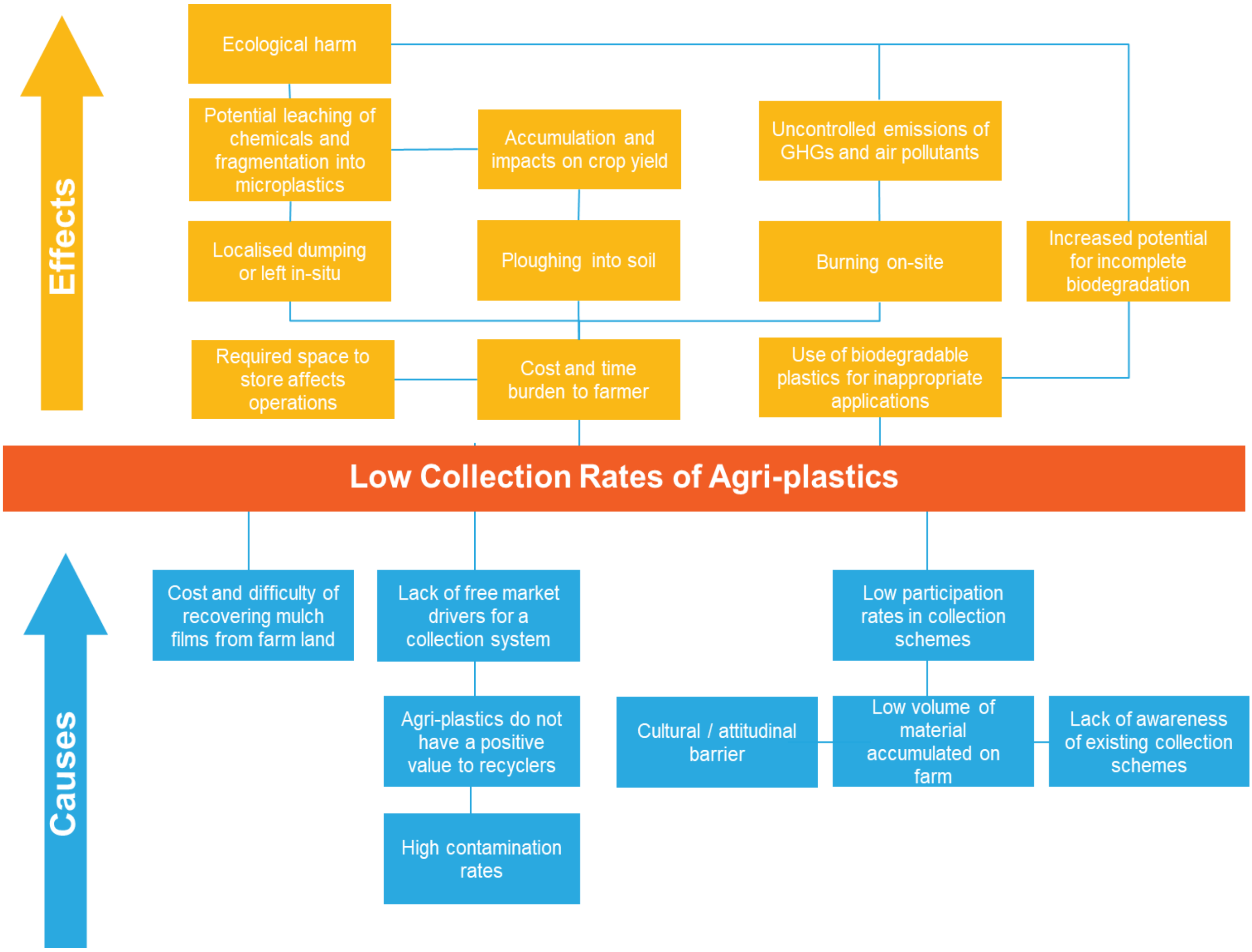
- **Insufficient economic and / or regulatory incentives for the separate collection of agri-plastic waste** (for example, most agri-plastic products – with a few exceptions – do not have a positive value for recyclers, and therefore there is little incentive for waste managers to collect it. The dynamics behind this are explored in more detail in Section 3.2.3);

And where a collection scheme exists:

- **Insufficient awareness among farmers of schemes in existence;** and
- **Insufficient incentives for all farmers to participate in the collection of agri-plastic waste** (for example, farmers may choose to burn their waste on site or drip feed into the household waste stream, especially for low volume agri-plastics such as netting and twine which are easier to mismanage discretely).

The problem tree associated with the collection of agri-plastics is shown in Figure 3-1. This shows how some of the key barriers to collection are interlinked and how these could lead to the negative effects which are discussed in more detail in Section 3.4.

Figure 3-1: Problem Tree for the Collection of Agri-plastics



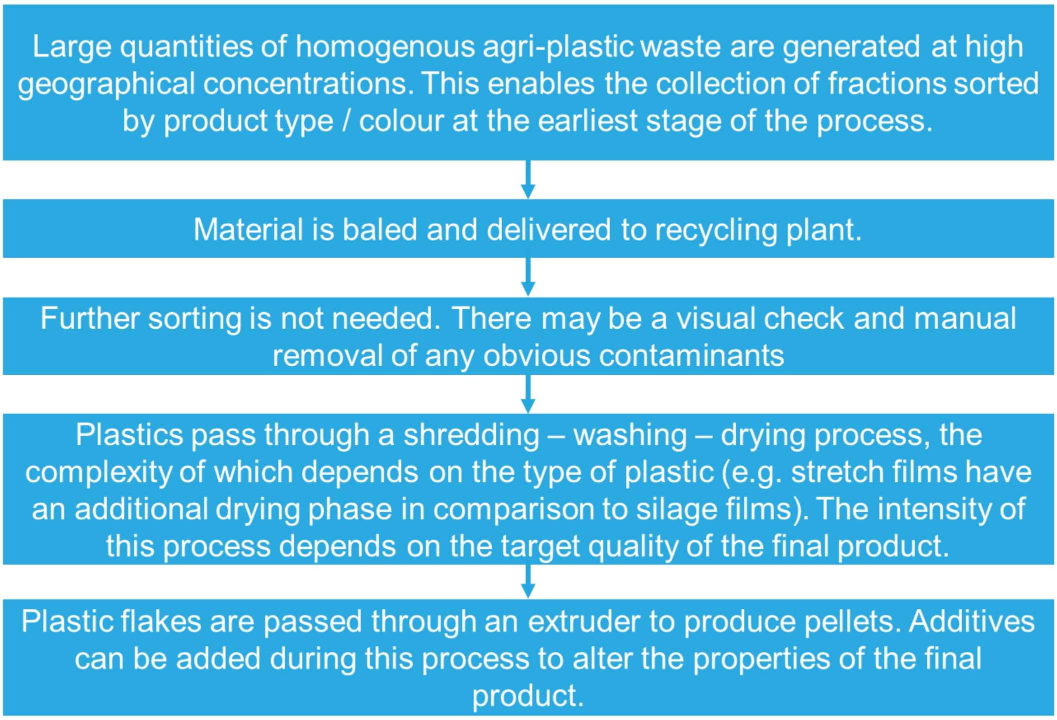
3.2 Recycling of Conventional Agri-plastics

As highlighted in Section 2.0, only 28% of the non-packaging APW collected in the EU is currently recycled (on the basis of APE information). This section explores the barriers to achieving higher recycling rates.

3.2.1 Agri-plastic Recycling Process

Mechanical recycling is the dominant process for recycling agri-plastics in Europe (chemical recycling for agri-plastic films has been trialled at a laboratory level, but is not commercially operational).[76] The typical mechanical recycling process for agri-plastics is shown in Figure 3-2:[77]

Figure 3-2: Agri-plastic mechanical recycling process



3.2.2 Design of Conventional Agri-plastics

It is important to first determine whether the design (i.e. the physical / chemical properties) of agricultural plastics allows them to be recycled. Briassoulis et al (2013) tested the intrinsic characteristics (e.g. tensile strength, moisture, foreign material content) of a range of agricultural plastics throughout use, storage, and transport, to determine the extent to which these characteristics may change over time and hinder

[76] Interview with Plastic Energy

[77] Briassoulis, D., Hiskakis, M., and Babou, E. (2013) Technical specifications for mechanical recycling of agricultural plastic waste, *Waste Management*, Vol.33, No.6, pp.1516–1530

the recyclability of the plastics.[78] The plastics studied included those used in greenhouses, high tunnels, low tunnels, mulching and silage films. The study found that the intrinsic characteristics of most of the agricultural plastics tested did not hamper their recyclability.

The same study also found that exposure of most plastics to UV radiation did not lead to degradation severe enough to interfere with their recyclability; an exception was observed for mulch films from Italy left in the field unprotected for five months.[79,80] **It is unclear how much of an issue this is for recyclers, though anecdotal evidence suggests that there are large volumes of mulch films that have been left exposed to UV in Italy/Spain and are no longer recyclable as they have become brittle and fragmented**.[81] Mulch films are often only used for one season and tend to be lower quality/thinner and less likely to include UV stabilisers, which may account for this particular issue being associated with this product type.

3.2.3 Profitability of Recycling Agri-Plastics

For the most part conventional agri-plastics can be *technically* recycled. However, recyclers have a choice in terms of the material they accept. For example, recyclers that recycle agri-plastic film, can often also recycle other film types (household, commercial, and post-industrial). A key factor in this decision is how profitable each type of plastic is to recycle – a calculation which is based on gate fees, cost of reprocessing (and disposal), and the value of the recyclate produced. **Currently, the high levels of contamination associated with agri-plastics and the lack of demand for the recyclate produced means recycling *most* types of agri-plastics is not an attractive or sustainable business venture.** This is explored further in the following section.

3.2.3.1 Contamination

High levels of contamination are a major problem associated with agricultural plastics. From a recyclers perspective it is the main factor that differentiates agricultural plastics from other types of plastic (e.g. household, commercial and post-industrial). Typical contaminants are sand, soil, organic matter and moisture, though anecdotal evidence also suggests that other miscellaneous items such as animal bones and metals can enter the stream.[82] Straw, wood and plant matter are the most problematic contaminants from a recyclers perspective. This material tends to float with the plastic, so is difficult to

[78] Briassoulis, D., Hiskakis, M., and Babou, E. (2013) Technical specifications for mechanical recycling of agricultural plastic waste, *Waste Management*, Vol.33, No.6, pp.1516–1530
[79] Briassoulis, D., Hiskakis, M., Babou, E., Antiohos, S.K., and Papadi, C. (2012) Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential, *Waste Management*, Vol.32, No.6, pp.1075–1090
[80] Briassoulis, D., Hiskakis, M., and Babou, E. (2013) Technical specifications for mechanical recycling of agricultural plastic waste, *Waste Management*, Vol.33, No.6, pp.1516–1530
[81] Interview with CEDO
[82] Interview with IFFPG

separate, and can end up in the flaked material as contamination. Levels of contamination vary by:

- **Type of agricultural plastics** (see Figure 2-8 in Section 2.5.4):
    - Mulch films are often heavily contaminated due to their direct contact with the soil. They are also thin, so the soil content to polymer ratio is high. Greenhouse film is typically the least contaminated film type as it comes into limited contact with soil / plants / silage and is relatively thick.
    - Bale nets tend to be contaminated with silage / straw to such an extent that they currently cannot be recycled in Europe (though the ADIVALOR scheme has invested in R&D to solve this issue, and hopes to have the first worldwide plant for recycling bale nets operational by 2023).[83] There is also an alternative product on the market called 'net-replacement film'. Anecdotally, it has been suggested that this is readily recyclable.[84] However, it currently represents only a small portion of the market (<5%), as it is more expensive than bale net, and is not proven to produce better quality silage.[85]
    - Irrigation pipes and tubes are made of thicker plastic material and therefore tend to have a lower rate of contamination in comparison to films.[86]
- **Crop type** (see Figure 3-3)**:** For example, mulch films used to grow asparagus and potatoes are associated with higher levels of contamination than films used to grow melons and strawberries—for every tonne of the latter, twice as much plastic material is recovered compared with the former.[87] Note that detailed information linking crop type to levels of contamination is not available.
- **Climate:** Wetter climates tend to produce more contaminated agri-plastics. In Ireland, it is estimated that 50% of total contamination of silage sheets / wrap is rainwater.[88]

There are some practices and technologies that can help to reduce contamination rates. Any practices that can be implemented prior to aggregation of material at a collection point are the most beneficial, as they reduce the need to transport contamination:

- **Storage practices**: Agri-plastics stored outside are likely to have a higher level of contamination (especially moisture) in comparison to those stored inside.[89] This practice is likely to be particularly beneficial in wet climates, like Ireland.

[83] Interview with APE Europe / ADIVALOR
[84] Interview with IFFPG
[85] Interview with Tama Europe
[86] Interview with ADIVALOR
[87] Based on data from APE Europe
[88] Interview with CEDO
[89] Interview with IFFPG

However, the IFFPG scheme has struggled to get farmers to adopt this behaviour, given current farming practices and the relatively low cost of the service.[90]

- **Method of mulch film removal from the field:**
  - Mulch films can be removed from the soil either manually or mechanically. There is some evidence to suggest that the mechanical removal of mulch films can reduce contamination rates in comparison to manual removal. A new type of mulch film removal technology ("RAFU" or "Recycling of Used Agricultural Films") has been trialled in France. It is a tractor attachment that mechanically cleans and rolls films as they are removed from the field (see Appendix A.3.2). Trial results have indicated that its use can reduce contamination from a factor of 3 to 4 times the original film weight to a factor of 1.4 to 1.7. The cost of the machine is estimated to be €25,000 - €30,000. For a large grower participating in the ADIVALOR scheme, payback could be within 3 years through savings on the weight based mulch film collection charges.[91]
  - There is no official data on the proportion of farmers using manual vs. mechanical removal techniques in the EU. Due to the expense of mechanical removal, it can be assumed that its use is limited to large farms only. Currently in France it is estimated that the RAFU technology is being used on ~50% of carrot hectares, but not yet on any other crops.[92] A Spanish distributor of farm machinery estimated that at least 90% of farm plastic removal occurs manually.[93]
  - Other practices such as irrigating mulch films several days before lifting to tenderise the soil adhered to the film and hanging plastics for one night before rolling can also help to reduce contamination.

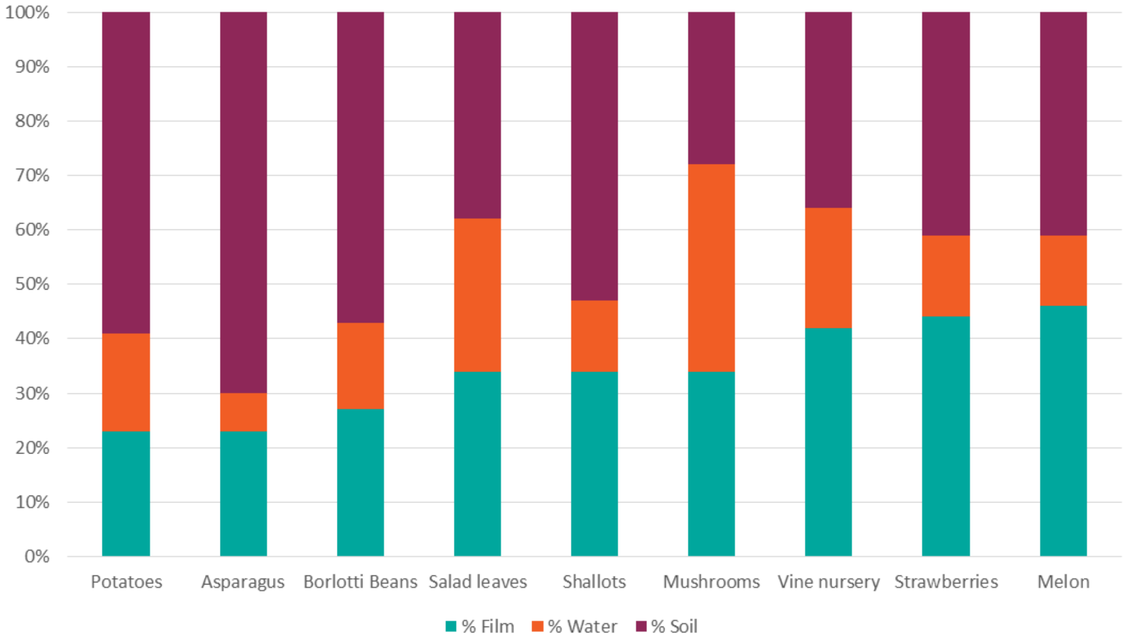
Despite these measures, there are some contaminants that are very difficult for a farmer to reduce prior to collection, in particular, small particles of soil, silage, clay, stone and manure, and therefore a level of contamination is unavoidable. Stakeholders suggest that even with the best practices applied, a contamination rate of 30% to 40% for mulch films is to be expected (and this lower limit depends on specific conditions such as crop, climate and soil type).[94]

In an attempt to solve this problem and increase mulch film recycling rates, ADIVALOR is investing €5 million in a 10,000 tonne capacity pre-treatment plant, which will shred, wash and dry mulch films to produce a 'clean flex' product that can be sold to recyclers.[95]

---

[90] Interview with IFFPG
[91] Interview with APE Europe
[92] Interview with ADIVALOR
[93] Interview with a Spanish distributor of farm machinery
[94] Interviews with ADIVALOR, GWC and MAPLA
[95] ADIVALOR (2019) Reach 100% Recycling of Mulch Films - Is It Possible?, 2019

Figure 3-3: Mulch Film Contamination Rate by Crop



Source: Adapted from APE Europe

From a purely technical perspective, recyclers can manage high levels of contamination. For example, recycling plants can deal with a feedstock with 60% or higher soil contamination and still produce a film stream suitable for extrusion into recycled pellet.[96] However, there is significant additional cost associated with reprocessing contaminated material:

- An intensive washing step must be included before processing, increasing capital and operational costs.[97]
- Contaminants such as sand can damage or erode the blades in equipment, increasing maintenance costs.[98]
- Recyclers need to bear the cost of disposing of contaminants once they are separated from the polymer (this can be thousands of tonnes of sand, stones, sludge and fines per year for a larger recycler, at a cost of €70 – €130 per tonne).[99]

---

[96] WRAP (2012) Film Reprocessing Technologies and Collection Schemes
[97] Briassoulis, D., Hiskakis, M., Babou, E., Antiohos, S.K., and Papadi, C. (2012) Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential, *Waste Management*, Vol.32, No.6, pp.1075–1090
[98] Briassoulis, D., Hiskakis, M., Babou, E., Antiohos, S.K., and Papadi, C. (2012) Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential, *Waste Management*, Vol.32, No.6, pp.1075–1090
[99] Interview with CEDO

- The efficiency of a recycling plant is also affected; yield rates (i.e. the tonnes of polymer output per tonnes of material input) are much lower for heavily contaminated plastics (see Table 3-1). The lower the yield rate, the higher the cost of producing each tonne of recyclate (as energy and time has to be spent removing non-target material). Typical yield rates of commercial and industrial films are 75 – 85%, compared to an average of 45 – 50% for agricultural films.[100]
- To a certain extent the yield rate is affected by material thickness. The typical thickness of agri-plastics received by recyclers varies by type of product, from 8µm for the thinnest stretch film to 300µm for greenhouse film.[101] This means that the surface area to mass ratio will influence the proportion of contamination i.e. thinner films are more likely to result in lower yields.

Table 3-1: Estimated Yield Rates, by Film Type

	Type of film	Yield per tonne of input	Thickness
Agricultural	Mulch	33 — 35%	15 – 20µm
	Stretch	45 – 50%	8 – 12µm
	Silage sheets	50%	100 – 180µm
	Tunnel	50%	20 – 50µm
	Greenhouse	60% — 70%	80 – 300µm
	Average	**45 – 50%**	**-**
Non-agricultural	Household	50%	-
	Commercial	75 – 80%	-
	Industrial	80 – 85%	-
	Production scrap	95%	-

Source: Expert opinion estimated by CEDO – a large EU plastics recycler

Table 3-2 shows that in some cases the cost to process the material comes close to or can exceed the sales prices and demonstrates why the level of contamination is often the difference between a profitable or loss making plastic waste stream. This is put in context with commercial and industrial (C&I) waste plastic films which are often similarly homogenous, but without the same level of contamination.

---

[100] Interview with CEDO
[101] Data from CEDO

Table 3-2: Costs and Revenues from Recycling Plastic Films (EUR/tonne)

		Agri-films	C&I films
Processing costs		380 - 480	280 – 300
Waste water treatment costs		20 – 25	-
Contaminant Disposal costs		70 – 130	50 – 60
Total costs		**470 - 635**	**330 – 360**
Recyclate sales price	Silage sheets	**550**	**550 – 670**
	Stretch film	**600 – 620**	

Source: Expert opinion estimated by CEDO – a large EU plastics recycler

3.2.3.2 Value of Agri-plastic Recyclate

The profitability of recycling agri-plastics depends on the value of the recyclate produced as well as the cost of recycling. Demand for recycled pellets depends on their quality, colour and their cost in comparison to virgin plastic.

Quality & colour

The quality of pellet produced from agricultural plastic is in general relatively poor, though does vary by type of input material.[102] For example:

- Most types of agri-plastics (mulch films, silage sheets and wrap, stretch film and irrigation piping) are dark in colour, which limits the applications the recyclate can be used in. There are some exceptions to this, including greenhouse and tunnel films.
- Multi-layer silage films have started to emerge on the European market, though are not currently widespread. These films contain a non-polyethylene layer (e.g. EVOH, nylon) designed to improve performance. However, when recycled, the resultant pellets will have weak spots, or “gels”. It is difficult for a recycler to determine how much of this type of material is in the input stream. One recycler mentioned that this limitation meant they can only recycle silage sheeting for use in thicker films (i.e. construction films of 250 – 300µm).[103]

---

[102] Interview with Berry BPI
[103] Interview with Berry BPI

- Stretch films have the best properties of all agri-films and produce the highest quality output (despite being more complicated to reprocess).[104]

In addition to quality limitations, buyers of recycled plastic are often more wary of pellets from agricultural sources due to concerns about their potential close contact with pesticides, odour etc.[105] The end markets for agri-plastic pellets are therefore very limited. The only common applications are refuse sacks, construction films and thick plastic profiles (e.g. 'plastic wood' for park benches).

Price vs. virgin plastic

The price of virgin plastic also has a strong influence on the demand for recycled plastic pellets. All things being equal, from a manufacturer's perspective using virgin plastic is easier than using recyclate – the supply is high quality and consistent, with no variation between batches. In general, if the virgin price is >€1,200 per tonne, manufacturers will choose to use recyclate, but recyclers will struggle to find outlets for pellets when virgin plastic is <€1000 per tonne.

Recycled Content

Given there are very limited end-markets for agri-plastic recyclate, the extent to which it is used in the manufacture of new agri-plastic products is key in terms of driving demand. Insight from a plastic recycler suggests that a minimum of 25% recycled content is possible in most agri-plastic applications, and potentially up to 70% for mulch films (mulch films do not need to be high quality and are only used for one growing season) (see Table 3-3 for further estimates).[106]

Table 3-3: Potential Recycled Content in Agri-films (estimate)

Film type	Potential recycled content
Stretch	20%
Greenhouse / tunnel	25%
Silage	50%
Mulch	70%

Source: CEDO

Historically, producers have been reluctant to market a product as containing recycled material, for fear of the perception that this reduces the quality of the product.[107] Some

[104] Interview with CEDO
[105] Interviews with CEDO & Plastic Energy
[106] Interview with CEDO
[107] Interview with IFFPG, RIGK & Tama Europe

types of agricultural plastics (e.g. silage wrap, bale nets, twine) are used by farmers in 'high stress' situations – i.e. there is short weather window in which to do the baling – and famers are reluctant to take a risk in terms of product quality.[108]

Though that is not to say that agri-plastic recyclate is not used at all in agri-plastics – insight from an agri-plastics recycler/producer suggests that some material is input back into thicker agri-films (i.e. >100µm).[109] Similarly, TAMA Europe is aware of a twine product which contains post-consumer recycled content (and does not appear to perform any differently to twine made without recycled content). The typical percentage mix of agri-plastic recycled content is not well known, largely because producers are reluctant to reveal this information to competitors.[110] Few, if any, producers have made commitments to a recycled content percentage input—doing so is a risk, as it would prevent them increasing the virgin plastic content when the oil price is low, driving up production costs in comparison to competitors.[111]

3.2.4 Summary of Recycling of Agri-plastics

In current market conditions producing recycled pellets from agri-plastic waste is a challenging business to make profitable, with the exception of greenhouse film, and in some circumstances, stretch film.[112] The cost of reprocessing and producing a pellet tends to outweigh its value (as shown in Table 3-2). In comparison, the cost of reprocessing and producing a pellet from C&I films is lower than the value of the pellet produced, and is therefore a more viable business venture. Recyclers therefore either stop accepting agri-plastic films in favour of other more profitable material such as C&I films, or introduce high gate fees in an attempt to break-even. The most successful agri-plastic recyclers are making agri-plastic pellets into a finished product such as refuse sacks (e.g. CEDO in the Netherlands or Berry BPI in the UK), and therefore do not need to find a buyer for the recyclate.[113]

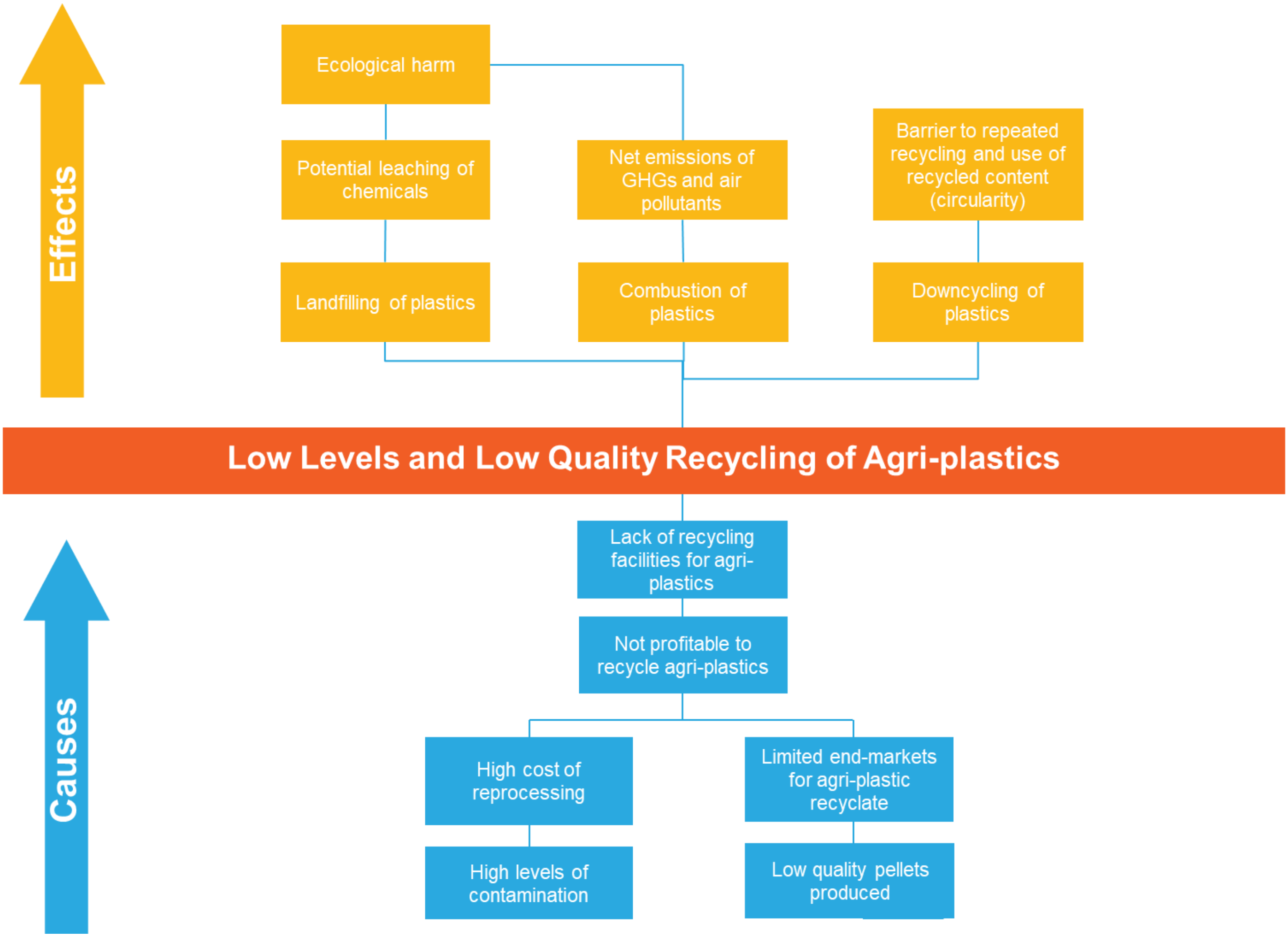
To summarize, the key barriers to recycling agri-plastics in Europe are:

- **High processing costs primarily due to high contamination rates**; and
- **Low value / limited end markets for recyclate.**

Figure 3-4 outlines the key barriers to recycling, as discussed in this section.

[108] Interview with TAMA Europe
[109] Interview with Berry BPI
[110] Interview with RIGK
[111] Interview with CEDO
[112] Interview with CEDO
[113] Interview with Berry BPI

Figure 3-4: Summary of Barriers to Recycling Agri-plastics



3.3 Summary of Barriers to Collection / Recycling by Product Type

As highlighted in the discussion so far, the qualities and characteristics of agri-plastics vary by product and this has an influence on the strength of barriers to recycling and collection. These variations are summarized below and visually in Table 3-4:

- **Greenhouse films / large tunnels** are thick and do not come into contact with the soil, so have a low contamination rate (and higher recycling yield). They are usually transparent and so produce a higher value recyclate than other agri-plastics. These films still have a positive value on the market and are in demand by recyclers. The economics of recycling greenhouse films are such that it is viable for private collection schemes to exist, even in countries such as France, where they must compete with national EPR scheme. Recognising these facts, ADIVALOR pays farmers €50 per tonne for this material.
- **Small tunnels** are thinner than greenhouse / large tunnel films, and have a higher contamination rate (and lower recycling yield). They tend to be translucid.

- **Mulch films** are mostly black, thin and low quality (due to only being required for one growing season), and have very high contamination rates. They are the most difficult type of agri-plastic to recycle and are expensive to transport (soil content can reach three times the weight of the plastic). As the material has no value, it is only collected by EPR schemes (collection rates under these schemes tends to be high, as farmers have limited other options for mulch film EOL management). As EN13655 is not a mandatory requirement, very thin films that are impossible to fully recover from the field are common. The contamination rate is also directly related to the thickness of the film, therefore to effectively recycle it on a significant scale there should be a minimum thickness requirement.
- **Silage sheeting** falls in the mid-range in terms of thickness and contamination rate. Where an EPR scheme exists for this material, collection rates are strong.
- **Stretch films** are the thinnest type of agri-plastics and relatively complex to recycle. However, the plastic properties are such that it produces the highest quality output. In some circumstances, recycling stretch films can be profitable.
- **Bale nets** are the most challenging agri-plastic material in terms of recycling. The nets tends to be contaminated with straw / silage / vegetal material which floats in water, and is therefore difficult to remove in a recycling process. There are no facilities in Europe that can recycle bale nets, though ADIVALOR is investing in R&D in this area, and hopes to have a functioning recycling plant in operation by 2023. Typically a farm will accumulate a relatively small volume of bale nets per year (<100k/yr in France), and this can limit collection rates even where an EPR scheme exists, as farmers can viably manage this material via other more convenient routes such as the household waste stream.
- **Twine** falls in the mid-range in terms of thickness and contamination rate. Similarly to bale nets, the low volumes accumulated on farms can be a barrier to high collection rates, even when an EPR scheme exists.
- **Irrigation pipes / drippers** are made from relatively thick plastic and have relatively low contamination rates compared to films (the lowest of all agri-plastics considered by APE Europe). ADIVALOR does not struggle to find recyclers for this type of plastic – there is demand for it from recyclers in Spain.

Table 3-4: Barriers to Collection/Recycling, by type of Agri-plastic Waste

✓ = low barrier; ✓✓ = medium barrier; ✓✓✓ = high barrier (indicative)

Category	High contamination	Dark colour	Thickness	Cost to recycle	Value of recyclate	Low volumes at farm
Greenhouse films / large tunnel	✓	Clear	✓	✓	✓	
Small tunnel	✓✓	Clear	✓✓	✓✓	✓✓	
Mulch films	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	
Silage sheet	✓✓	✓✓✓	✓✓	✓✓	✓✓✓	
Stretch films	✓✓	✓✓✓	✓✓✓	✓✓	✓✓	
Bale nets	Mostly straw = very problematic	✓✓	N/A	Unrecyclable	Unrecyclable	✓✓✓
Twine	✓✓	✓✓	N/A	✓✓	✓✓	✓✓✓
Irrigation pipes / drippers	✓	✓✓✓	✓	✓	✓	

The potential policy measures which may help overcome these barriers and increase the separate collection and recycling of agri-plastics are discussed in Section 6.0

Box 3-3: Key challenges for agri-plastics recycling in Europe

A better quality of waste needed

One of the major challenges that agricultural film recycling in Europe is facing today is the quality of the collected material. Since the Chinese ban on plastic waste imports became effective, high-quality film material from post-consumer streams has become more available in Europe. This material became the preferred stream of recyclers as the contamination of the agricultural waste is much higher and therefore more costly to recycle. **Agricultural film recyclers are currently struggling with low quality contaminated inputs. This in turn has a negative impact on the efficiency of the recycling process, as a significant proportion of the input material must be rejected and is lost, and also results in very high maintenance and disposal costs.** Additionally, output material from this stream is lower quality and therefore, lower margins can be achieved. Increase in the quality of the collected material should result therefore, in lowering the overall recycling costs, increase in the recycling efficiency and driving more investment.

Collection and quality of plastic waste go hand in hand

Collection is the first step in ensuring that the material will be recycled. There is a lack of dedicated collection points for agricultural plastics across Member States. Increasing the tonnages of collected waste is a must to safeguard steady flow of materials for recyclers and guarantee their proper functioning. Additionally, the collected waste must be sorted and pre-cleaned so that the input material that recyclers receive is of higher quality.

Secondary raw material market needs to be boosted

There is a strong need to boost the market for recycled agri-plastics in Europe. Virgin material is more attractive compared to PCR in terms of costs. Some incentives e.g. regulation on ecodesign for their agri-plastic products, are needed to boost the market for PCR. Hence there is a need of mapping the final applications of recycled material from agricultural plastics, either to ensure traceability or to implement adequate policy measures. For now, the main applications are waste bags (accounting for more than 70% of recycled agricultural films) and pallet films and to a lesser extent agricultural film. Some new applications with higher added value are needed. In addition, plastics for agriculture require particular characteristics in terms of transparency, UV resistance, and strength etc. Recycled material is often not capable of reaching these requirements for certain applications such as greenhouses or nets. Therefore, there are few secondary raw materials used in agriculture.

Investments

State of the art collection and sorting recycling technologies must be applied and further investments in new technologies made to further the quality of the recycled material so that it can be used in high end applications. Additionally, pre-treatment (e.g. pre-cleaning) steps will also need to be introduced to increase the quality of waste and minimize the contamination of the recyclers' input material. This includes investment at the farm level where equipment can be used to remove the contamination before it is shipped any distance.

Value chain collaboration

The success of agricultural plastics recycling is a matter of the whole value chain including agricultural plastic producers, collectors, farmers and recyclers among others. Only via collaborative action can the recycling rate be improved.

3.4 Environmental Impacts of Improper Collection and Low Recycling / Re-use Rates

3.4.1 Impacts of Improper Collection

One of the aims of this work is to examine the environmental impacts of the improper collection of agricultural plastics (i.e. what happens when they are left in the environment). The majority of academic research in this area has focused on plastic mulch film residues, likely because mulch films are widely used (they make up the largest proportion of covered agricultural surface in Europe), and are also more likely than other types of agricultural plastics to be left in the environment (they are applied directly to the soil, and can be difficult to fully recover).[114]

3.4.1.1 Accumulation in Soil

This section summarises the evidence base for the impact of agricultural plastic residues (e.g. microplastics) on soil health. It is based on a review of relevant academic literature. Only papers that explicitly focused on the impact of agricultural plastic residue on soil health were considered (i.e. the review did not include papers which looked at the impacts of 'plastics' or 'microplastics' on soil health more generally).

If mulch films are not properly collected (either by design or accident), plastic remains in the soil. Most mulch films are made of polyethylene (PE), which is resistant to hydrolysis and not readily attacked by micro-organisms, so these mulch films can take an extremely long time to degrade in the environment.[114] For example, laboratory experiments have shown that LDPE buried in soil reduced its weight by only 0.2% per year.[115] While, a review of plastic litter breakdown by Sundt et al (2014) suggested an estimated 300 years for total degradation of polyethylene in soil.[116]

Mulching film left in the soil can fragment over time, forming plastic residues of various sizes (from 700 μm^2 to 2,850 cm^2). [117] Those fragments <5mm in length are termed microplastics. Repeated years of improper collection of mulch films is therefore highly likely to lead to an accumulation of plastic residue (including microplastics) in the soil. He et al (2018) proposed a two-step accumulation model based on an examination of

---

[114] Steinmetz, Z., Wollmann, C., Schaefer, M., et al. (2016) Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?, *The Science of the Total Environment*, Vol.550, pp.690–705

[115] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., and Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, *Science of The Total Environment*, Vol.651, pp.484–492

[116] Lassen et al. (2015) *Microplastics: Occurrence, effects and sources of releases to the environment in Denmark*, 2015, https://backend.orbit.dtu.dk/ws/portalfiles/portal/118180844/Lassen_et_al._2015.pdf

[117] Steinmetz, Z., Wollmann, C., Schaefer, M., et al. (2016) Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?, *The Science of the Total Environment*, Vol.550, pp.690–705

distribution patterns of residual plastic film in six cotton fields in northwest China. For the first c15 years of mulching cultivation, accumulation of larger (>25mg) plastic fragments was relatively constant, while accumulation of smaller fragments (<25 mg) was lower. After 15 years of mulching practice, the larger fragments began to break down into smaller pieces, and accumulation of smaller fragments increased, as did their movement towards deeper soils.[118]

The identification, extraction and quantification of microplastics from soil is more complex than from aquatic environments, where much of the research into microplastics to date has taken place. [119] Though work is being undertaken to develop appropriate techniques for measuring the occurrence of microplastics in soil, no standard method exists.[120] There is therefore very limited field data available for the concentration of conventional plastics in agricultural soils.

The data that does exist is from China, the world's largest user of plastic mulch film.[121] Studies indicate that the average concentration of residual plastic film ranges from 50 to 260 kg/ha in areas where there has been long-term use of mulch films (>10 years).[122] Some studies reference China's 'national standard' as 75kg/ha.[123,124] However, it is not clear how comparable the situation in China is with the rest of the world, including Europe. There are a number of factors which affect concentrations of microplastics in soil, including climate characteristics, film thickness, mulching time, crop type, covering ratio and end-of-life management method.[125] In some areas of China, mulch films have been in use for almost 30 years, and the recovery rate of such films has been low (due to labour requirements, inefficient recovery machinery and a lack of mandatory recycling

---

[118] He, H., Wang, Z., Guo, L., Zheng, X., Zhang, J., Li, W., and Fan, B. (2018) Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem, *Soil and Tillage Research*, Vol.180, pp.194–203

[119] Qi, R., Jones, D.L., Li, Z., Liu, Q., and Yan, C. (2020) Behavior of microplastics and plastic film residues in the soil environment: A critical review, *Science of The Total Environment*, Vol.703, p.134722

[120] Zhang, S., Yang, X., Gertsen, H., Peters, P., Salánki, T., and Geissen, V. (2018) A simple method for the extraction and identification of light density microplastics from soil, *Science of The Total Environment*, Vol.616–617, pp.1056–1065

[121] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., and Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, *Science of The Total Environment*, Vol.651, pp.484–492

[122] Liu, E.K., He, W.Q., and Yan, C.R. (2014) 'White revolution' to 'white pollution'—agricultural plastic film mulch in China, *Environmental Research Letters*, Vol.9, No.9, p.091001

[123] He, H., Wang, Z., Guo, L., Zheng, X., Zhang, J., Li, W., and Fan, B. (2018) Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem, *Soil and Tillage Research*, Vol.180, pp.194–203

[124] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., and Wang, H. (2016) The status and distribution characteristics of residual mulching film in Xinjiang, China, *Journal of Integrative Agriculture*, Vol.15, No.11, pp.2639–2646

[125] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., and Wang, H. (2016) The status and distribution characteristics of residual mulching film in Xinjiang, China, *Journal of Integrative Agriculture*, Vol.15, No.11, pp.2639–2646

policies).[126,127] Also, the mulch film currently used in China is 6-8µm thick, whereas the mulch film used in Europe tends to be thicker, generally at around 15-20µm. Thicker mulch film is more likely to remain intact after use, and therefore is easier to recover. Based on this knowledge, it could be assumed that the concentrations of plastic in agricultural soils in China are likely to be higher than those in Europe. However, as identified in Section 3.1.1, there is no reliable data available that for the proportion of mulch film that remains after collection in any EU country.

Furthermore, it is important to note that mulch films, whilst significant, are not the only pathway through which plastics can enter agricultural soils. Other routes include municipal waste, biosolids (sewage sludge and anaerobic digestate), plastic coated fertilizers and atmospheric deposition.[128] Therefore, even if the overall concentration of plastic in agricultural soils is quantified, it is likely to be difficult to determine the proportion that originated from mulch films.

Limitations of the Evidence Base

Knowledge about the long-term effects of plastic residues on soil health is relatively sparse and somewhat contradictory. Solitary field or laboratory-based experiments cannot be used as evidence to evaluate the effects of plastic residue on soil health on a regional or national scale.[129] It is unknown how specific the results are to the circumstances being tested (reported effects could differ by many factors including climate, soil type, crop species, film type, mulching method etc.), and therefore it is unclear how applicable the results are to other contexts. Furthermore, results are often not put into the wider context – it can be difficult to assess what certain findings mean in reality (e.g. how will crop yield be affected). However, the evidence does provide an idea of the direction (i.e. positive, neutral or negative) of the impact of plastic residue on soil health.

Impacts on Soil Physical Properties

One of the ways in which plastic residues can influence soil health is by altering the physical structure of the soil, and by extension interfering with water and nutrient transport. A limited number of studies have investigated this. For example, Jiang et al (2017) tracked water movement in two soil plots in north-western China: in one plot, plastic film fragments were cleared during ploughing, while in the other they were

[126] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., and Wang, H. (2016) The status and distribution characteristics of residual mulching film in Xinjiang, China, *Journal of Integrative Agriculture*, Vol.15, No.11, pp.2639–2646

[127] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., and Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, *Science of The Total Environment*, Vol.651, pp.484–492

[128] Qi, R., Jones, D.L., Li, Z., Liu, Q., and Yan, C. (2020) Behavior of microplastics and plastic film residues in the soil environment: A critical review, *Science of The Total Environment*, Vol.703, p.134722

[129] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., and Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, *Science of The Total Environment*, Vol.651, pp.484–492

retained.[130] Comparative results indicated that the presence of plastic film fragments significantly influenced soil physical properties, including bulk density and total porosity. In particular, the correspondence between water flow pathways and the maize root zone decreased, thus limiting water use efficiency. The study concluded that the greater the amount of plastic fragments in the soil, the lower the volume and rate of water infiltration, and that this phenomenon is likely to affect crops with fibrous root systems (e.g. wheat and corn) more than those with taproot systems (e.g. cotton) which can extend to deeper soil layers to absorb water. Note though, that the mass and volume of plastic fragments present in the study were not measured, and therefore, effects cannot be linked to a certain concentration of plastic in the soil.

Yuanqiao et al (2017) conducted a lab experiment which tested how residual film influenced the transportation of water and nitrate in soil at 6 difference concentrations (from 0 to 720g/ha). The results showed that plastic-film residues can prevent the movement of the wetting front and make the wetted volume irregular.[131] Similarly, Bai et al (2019) found that for a given irrigation time, an increase in plastic film residues slows water movement in the soil (five different concentrations of residual film were tested from 0 – 800kg/ha).[132] Note that the upper limit of plastic residue concentrations tested are far higher than what has been observed in China.[133]

In summary, evidence does suggest that plastic residues have an impact on soil physical structure.

Impacts on Soil Organisms

Very small fragments of plastic (e.g. <1mm) are small enough to be taken up by soil biota, like earthworms and mites.[134] These mesofauna are critical to maintaining soil quality, for example by creating channels for water flow and root growth, and incorporating leaf litter and crop residues into the soil.[135] Laboratory experiments have shown that microplastics can influence earthworm growth and mortality. Cao et al (2017) kept earthworms in beakers with various concentrations of polystyrene microplastics (0%, 0.25%, 0.5%, 1% and 2% of the soil). Exposure at the higher rates (1%

---

[130] Jiang, X.J., Liu, W., Wang, E., Zhou, T., and Xin, P. (2017) Residual plastic mulch fragments effects on soil physical properties and water flow behavior in the Minqin Oasis, northwestern China, *Soil and Tillage Research*, Vol.166, pp.100–107

[131] Yuanqiao, L., Caixia, Z., Changrong, Y., Lili, M., Qi, L., Zhen, L., and Wenqing, H. (2020) Effects of agricultural plastic film residues on transportation and distribution of water and nitrate in soil, *Chemosphere*, Vol.242, p.125131

[132] Bai et al (2019) Study on the influence of different agricultural residue film amounts on soil infiltration process of light sierozem,

[133] Liu, E.K., He, W.Q., and Yan, C.R. (2014) 'White revolution' to 'white pollution'—agricultural plastic film mulch in China, *Environmental Research Letters*, Vol.9, No.9, p.091001

[134] Rillig, M.C. (2012) Microplastic in Terrestrial Ecosystems and the Soil?, *Environmental Science & Technology*, Vol.46, No.12, pp.6453–6454

[135] *Earthworms for Soil Health | Helping farmers in Scotland | Farm Advisory Service*, accessed 12 March 2020, https://www.fas.scot/news/earthworms-for-soil-health/

and 2%) significantly inhibited the growth of the earthworms, while at the 2% treatment, the mortality rate was 40%. Huerta Lwanga et al (2016) also studied the impact of microplastics on earthworms, at a variety of concentrations (7% to 60% dry weight). After 60 days, the earthworms at >28% concentration showed a higher mortality and lower growth rate compared to the control experiment (though it is important to note that this study used microplastic concentrations 1000-fold higher than found in plastic contaminated agricultural soils).[136,137] The theory is that microplastics accumulate in the earthworm's gut, causing damage to their immune systems and affecting their feeding behaviour.

Impacts on Crop Yield

Clearly there are many studies which indicate that plastic residues have the potential to alter soil properties. What is key, though, is to understand how crop yields are ultimately affected. Again, most data that relates to this is from studies conducted in China. Gao et al (2019) conducted a meta-analysis of 266 studies involving 3,160 observations in China to analyse the effects of plastic mulching residue on crop yield for maize, potato and cotton. The results showed that when the residual amount of plastic film was below 240kg/ha, the effects on crop yield were not significant. However, when the residual plastic reached 240kg/ha, crop yield was reduced by 11.27% for 240 – 480 kg/h,; and 24.26% for >480 kg/ha. However, some studies showed no significant effect on yield even when the residual amount of plastic film was up to 720kg/ha which demonstrates the significant variability this is possible.[138] Comparing these results with the levels of plastic residue observed in China (50 – 260kg/ha), it seems that only at the very upper end of the spectrum crop yields are affected (though of course this is a generalisation).

The exact reasons for crop yield reduction are unclear. Soil bulk density was found to be reduced by the presence of high concentrations of microplastics; this in turn reduced the velocity of soil water flow which may affect the yields of crops with fibrous root systems in particular (e.g. wheat, rice, maize, strawberries and some varieties of tomato). The relationship between plastic residue and crop yield is unlikely to be a simple one, will depend on multiple factors and is largely unknown. More research is required to understand whether crop yield is linearly related to the amount of plastic residue in soil, and if not, what the 'tipping' point is at which plastic residue can significantly reduce crop yield. The exact mechanism for this impact also requires further investigation.

---

[136] Huerta Lwanga, E., Gertsen, H., Gooren, H., et al. (2016) Microplastics in the Terrestrial Ecosystem: Implications for *Lumbricus terrestris* (Oligochaeta, Lumbricidae), *Environmental Science & Technology*, Vol.50, No.5, pp.2685–2691

[137] Qi, R., Jones, D.L., Li, Z., Liu, Q., and Yan, C. (2020) Behavior of microplastics and plastic film residues in the soil environment: A critical review, *Science of The Total Environment*, Vol.703, p.134722

[138] Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., and Li, Z. (2019) Effects of plastic mulching and plastic residue on agricultural production: A meta-analysis, *Science of The Total Environment*, Vol.651, pp.484–492

Despite this, the current data can be used to model the potential for plastic accumulation to provide some context for how likely these concentrations are in reality. An LDPE mulch film of 20µm equates to a mass of 139 kg/hectare assuming a 75% coverage.[139] As discussed in Section 3.1.1, obtaining accurate rates for retrieval of mulch film from the field is difficult due to the number of factors affecting this such as crop type, film thickness/quality and the ground conditions at the time. With the available data from China and expert judgements from Europe (Section 3.1.1), a range of 75-95% is likely to encompass all realistic scenarios currently. In Figure 3-5 the potential accumulation is shown when mulch films are applied annually with a fallow period every third year. With a 75% field recovery rate the 240kg/hectare threshold is reached in 11 years and the 480kg/hectare threshold in 21 years. A 90% removal doubles this time period and a 95% and 97.5% recovery rate successively doubles the time further—this demonstrates how each percentage point improvement above 90% is likely to have a significant difference in the levels of plastic pollution.

To put this further into context; if a 75-95% mulch film field recovery rate (not to be confused with a collection rate) averaged across the EU, the use of 83,000 tonnes of mulch film annually would result in 20,750 - 4,750 tonnes of conventional plastic remaining on agricultural land every year. A 99% recovery rate would be the equivalent of 830 tonnes remaining.

To put this further into context in comparison it is worth reflecting on plastics legislation that has already been enacted, namely the 'Single Use Plastics' Directive.[140] The Directive was based upon an impact assessment which provided scenarios that estimated a reduction of marine plastic litter of between 2,750 and 12,000 tonnes annually.[141]

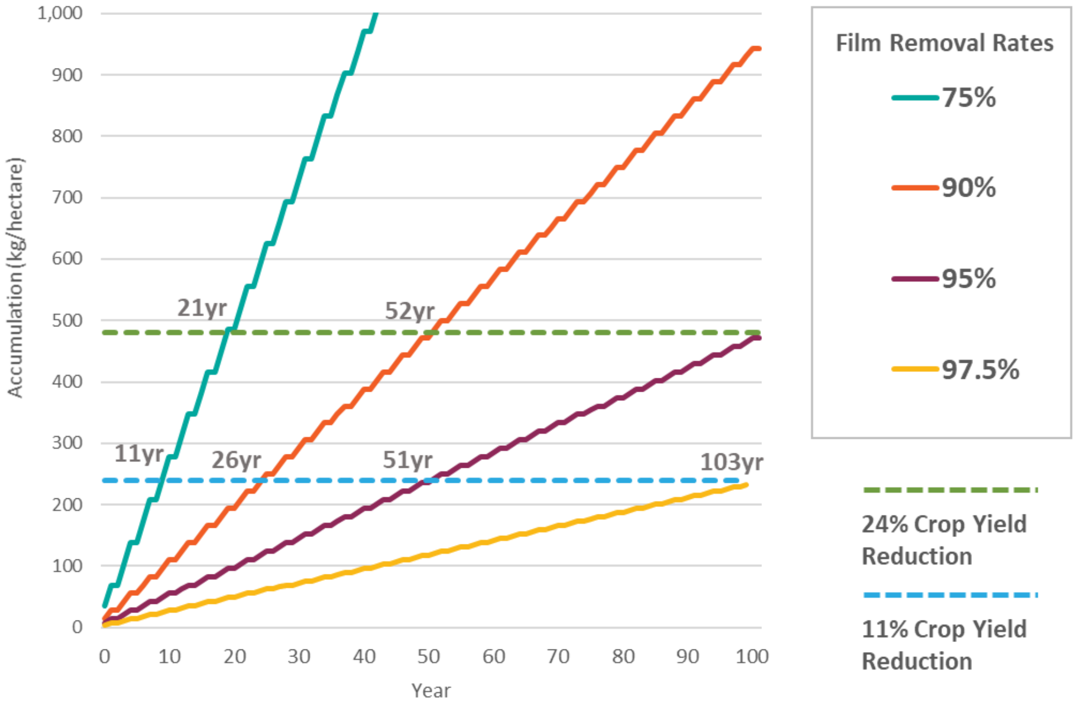
---

[139] Coverage can be in the range of 40-80% depending upon specific application - http://www.vinmarpolymerproducts.com/mulch-films.html

[140] European Commission (2019) Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment

[141] Eunomia Research & Consulting (2018) *Plastics: Reuse, recycling and marine litter – Impact assessment of measures to reduce litter from single use plastics*, Report for DG Environment, 2018, http://publications.europa.eu/publication/manifestation_identifier/PUB_KH0318234ENN

Figure 3-5: Conventional Plastic Mulch Film Accumulation Model



At present it is not possible to determine how much plastic in agricultural land would end up in waterways (including the marine environment). Spatial modelling has been conducted for other plastic emissions, such as particles emitted from vehicle tyre abrasion.[142,143] However, the driving activity data and tyre wear rates have been studied for many years to form the basis of such an analysis. This has yet to be undertaken for plastics in agricultural soils.

There are two gaps in understanding currently; the mass of plastic material that is left on the field and its fate over an extended period of time. These gaps might be filled with the following:

- Soil sampling linked to known levels of application (using a similar methodology to Zhyang et al from China.[144]) and/or a study to analyse and record how much plastic is removed annually from a field for different crops, conditions and

---

[142] Cardno ChemRisk (2017) Preliminary Tyre and Road Wear Particle Environmental Fate Assessment
[143] University of Plymouth, Newcastle University, King's College London, and Eunomia Research & Consulting (2019) *Investigating the sources and pathways of synthetic fibre and vehicle tyre wear contamination into the marine environment*, 2019
[144] Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., and Wang, H. (2016) The status and distribution characteristics of residual mulching film in Xinjiang, China, *Journal of Integrative Agriculture*, Vol.15, No.11, pp.2639–2646

practices. The former being longer term, but the latter could be conducted over one season.

- A spatial model of potential flows from agricultural land to waterways that takes into account the location of farms in relationship to waterways, soil erosion and rain events.

3.4.2 Loss of Soil Organic Carbon (SOC)

As identified in Section 2.5.3 there is a considerable amount of soil that becomes incorporated with any plastic that is collected. This is estimated to be around 312 kt per year in the EU, with 43% (133 kt) of this coming from mulch film collection.

The removal of soil from fields contributes to the loss of soil organic carbon (SOC). SOC is the largest terrestrial sync for carbon and is a key constituent of soil organic matter (SOM) which provides stabilisation of soil structure, retention and release of plant nutrients and maintenance of water-holding capacity.[145]

The SOC content of soil is extremely variable and dependant on a number of factors, but data suggest around 77% of European soils contain between 1-6% SOC, although for southern Europe including much of Spain and Italy the average is less than 2% due to the rapid mineralisation of SOC for the high temperatures in Summer.[146] This means that between 6-19 kt of SOC are removed from EU soils every year from agri-plastics collection. As maintaining SOC in soil improves soil health the removal of it from agricultural soils should be avoided if at all possible.

3.4.3 Open-burning of Agri-Plastics

If agri-plastics are not formally collected there is a possibility that they may be burnt on-site. The quantitative evidence on open-burning of agri-plastics is limited, but anecdotal comments from stakeholders indicates that this practice does take place. The uncontrolled burning of plastic waste is a major source of air pollution: by-products include soot, solid residue ash, black carbon, and toxic pollutants like dioxins, furans, mercury, polychlorinated biphenyls and polycyclic aromatic hydrocarbons (PAH's).[147] These substances are harmful to both the environment and human health. For example, black carbon has a global warming potential of up to 5000 times greater than carbon

[145] FAO/GSP(2017) *Soil Organic Carbon - the hidden potential*, Rome, Italy: FAO

[146] Ezio Rusco, Robert Jones, and Giovanni Bidoglio (2001) *Organic matter in the soils of Europe: Present status and future trends*, Report for European Commission Joint Research Centre, October 2001, https://esdac.jrc.ec.europa.eu/content/organic-matter-soils-europe-present-status-and-future-trends

[147] Verma, R., Vinoda, K.S., Papireddy, M., and Gowda, A.N.S. (2016) Toxic Pollutants from Plastic Waste - A Review, *Procedia Environmental Sciences*, Vol.35, pp.701–708

dioxide.[148] While pollutants such as PAH's and dioxins are carcinogenic and associated with health impacts, including cancer.[149]

3.4.4 Summary of Environmental Impacts of Improper Collection and Low Recycling / Reuse Rates

The improper collection of agri-plastics is likely to lead to negative environmental impacts. Firstly, there is a greater chance that plastic residue will enter and remain in soil if it is not collected. The existing evidence base examining the impact of plastic residues on soil suggests that, at some point, when concentrations reach a certain threshold, negative impacts on soil fertility and crop yield are likely to occur. Modelling of likely scenarios for the use of mulch film suggest that such thresholds could be met within 11-51 years at recover rates (not to be confused with a collection rate) of 75-95%. To put this into context; if a 75-95% mulch film field recovery rate averaged across the EU, the use of 83,000 tonnes of mulch film annually would result in 20,750 - 4,750 tonnes of conventional plastic remaining on agricultural land every year. At this time, it is unclear what recovery rates are likely if best and typical practice is employed.

Furthermore, a considerable amount of soil becomes incorporated plastic that is recovered from the field. This soil is estimated to be around 467 kt per year in the EU, with 36% (166 kt) of this coming from mulch film collection despite only accounting for 12% of the market (see Figure 2-6 in Section 2.5.3). The removal of soil from fields contributes to the loss of soil organic carbon (SOC) – a key component of soil health.

Low collection rates also increase the likelihood of agri-plastics being burnt in the open. This practice is associated with the release of by-products which have a significant potential to contribute to global warming, as well as links to negative impacts on human health. The open-burning of agri-plastics should also be avoided.

Finally, the likelihood and exact pathways for the transportation of plastic residues from soil to other environments (e.g. waterways) has not been studied and therefore further research is needed which should include:

- Soil sampling linked to known levels of application and/or a study to analyse and record how much plastic is removed annually from a field for different crops, conditions and practices. The former being longer term, but the latter could be conducted over one season.
- A spatial model of potential flows from agricultural land to waterways that takes into account the location of farms in relationship to waterways, soil erosion and rain events

[148] Reyna-Bensusan, N., Wilson, D.C., Davy, P.M., Fuller, G.W., Fowler, G.D., and Smith, S.R. (2019) Experimental measurements of black carbon emission factors to estimate the global impact of uncontrolled burning of waste, *Atmospheric Environment*, Vol.213, pp.629–639

[149] Verma, R., Vinoda, K.S., Papireddy, M., and Gowda, A.N.S. (2016) Toxic Pollutants from Plastic Waste - A Review, *Procedia Environmental Sciences*, Vol.35, pp.701–708

4.0 Aspects of End-of-Life of Biodegradable Agri-Plastics

Section 3.4 has demonstrated that the increasing use of conventional plastic in agriculture has led to substantial environmental issues where collection is limited, and the risk of plastics ending up in the environment is high. Plastics that biodegrade in soil in a short time frame offer a potential route for minimising the negative environmental effects of conventional plastic at end of life.

The main application of biodegradable agri-plastics (BDAPs) is mulch films. Substituting LDPE films for BDAPs avoids an accumulation of LDPE plastic fragments in the soil and also reduces the loss of soil and organic matter that occurs when LDPE films are removed. Where BDAPs are made from bio-based feedstock, substituting LDPE for these will also reduce consumption of fossil fuels. Putting plastic into the environment is not without risk and there is a challenge for regulators in assessing whether the existing standards are satisfactory in ensuring there are no unforeseen negative environmental consequences in the long term through the increased use of BDAPs in agriculture.

The aim of this section is to undertake an assessment of the benefits and risks of using BDAPs in comparison to conventional plastic alternatives in order to produce recommendations for the beneficial use of biodegradable plastics in agriculture.

Current consumption of BDAPs is low, comprising only 0.7% of all non-packaging agri-plastics used in the EU.[150] Within the category of mulch films, which are the main commercially sold product of biodegradable agri-plastics, this proportion increases to 5%.[151] Recent estimates of weights of biodegradable mulch films (BDM) sold in Europe range between 4000 and 5000 tonnes.[152] The primary markets for BDMs are in Italy, Spain, France, Germany, and Belgium, which (except for Belgium) are also the countries that dominate the conventional agri-plastics market.[153] The exception is the UK, which is the fifth largest consumer of agri-plastics but does not currently show a strong use of

---

[150] APE (2019) *Plastics - the Facts 2019, Analysis of European plastics production.*, accessed 9 May 2020, https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

[151] Novamont (2020) *Biodegradable Mulch Films: State of Art* Document provided for this Study and sent by email.

[152] Bioplastiche Italian Association for Bioplastics and Biodegradable Compostable Materials (2020) *Info on Biodegradable Mulch Films*. Document provided for this Study and sent by email

[153] Cicloplast (2017) *Situacion Actual De La Gestion De Plasticos Agricolas En España Y En Europa* *https://www.miteco.gob.es/es/ceneam/grupos-de-trabajo-y-seminarios/Proteccion-del-medio-marino/5plasticos-agricolas-cicloagro_tcm30-429451.pdf*

BDAPs. The low use of BDAPs can, in part, be explained by their higher cost in comparison to conventional films.

The first section outlines the main uses of BDAPs and the different types of materials available (Section 4.1). The agronomic performance of BDAPs is explored in Section 4.2 to see where they can be a substitute for conventional films with minimal loss of benefit. The safe use of these materials rests on their biodegradability and the evidence for this is reviewed in Section 4.3, to allow a discussion on the suitability of the current EU standard for biodegradable mulch films (EN 17033) in Section 4.5. Each of these sections are used to inform Section 4.7 on the development of criteria for the beneficial use of BDAPs.

4.1 Applications for BDAPs

There is an ever-increasing range of BDAPs commercially available, which combine polymers and additives with the aim of giving the best performance for different applications in different climates. In their design, BDAPs need to balance functionality with the capacity to biodegrade, so for a particular application the thinnest material that functions well is ideal. This also helps to keep the costs of BDAPs as low as possible.

As the range of specialised products increases, novel uses for BDAPs are being explored, in some cases where there was no prior use of conventional plastics, such as rice production. The appropriateness of these applications needs to consider whether BDAPs offer environmental or agronomic benefits sufficient to justify the extra use of plastics in agriculture. These issues are explored further in Section 4.2.2.

4.1.1 Mulch Films

The most common use of biodegradable plastics in agriculture is as mulch film in annual vegetable and fruit production. It is estimated that 5kt of BDMs are used each year,[154] which is 5% of European mulch film usage overall. [155] Most of this is clustered in Italy (2kt) and Spain (1.5kt). [156]

Common crops that can use BDMs are tomatoes, lettuce, peppers, aubergines, courgettes, strawberries and melons. Biodegradable materials are particularly suited to this application as the useable lifespan of the product is short (3-9 months), after which the product can be tilled into the soil and left to biodegrade. BDMs are used on crops in the open field as well as crops in greenhouses or tunnels.

---

[154] Bioplastiche Italian Association for Bioplastics and biodegradable compostable materials (2020) Info on Biodegradable Mulch Films For EU Study on conventional and biodegradable plastics in agriculture

[155] Novamont (2020) *Biodegradable Mulch Films: State of Art* Document provided for this Study and sent by email.

[156] Bioplastiche Italian Association for Bioplastics and biodegradable compostable materials (2020) Info on Biodegradable Mulch Films For EU Study on conventional and biodegradable plastics in agriculture

There is work exploring the use of BDMs as mulches for perennial fruit cultivation applications such as raspberries and grapes. Trials have shown that mulches increase yields when laid around young plants, and BDMs are deemed preferable to conventional films as it is very difficult to remove the films once the plants are established. [157]

4.1.2 Other Applications for BDAPs

Beyond use in mulch films there are various other applications that are currently being developed or have been trialled in the past. Importantly, testing has primarily focused on whether the material can perform similarly to conventional plastic during use and not whether subsequent biodegradation is beneficial from an end-of-life perspective.

There has been some testing of BDAPs used for low tunnel applications in Spain, but this is not current practice amongst growers. Low tunnel films are widely used for crops such as tomatoes, peppers, and melons where it is desirable to alter the microclimate of the air surrounding the crop rather than the soil, creating a mini greenhouse effect. Clear films are needed for this application and currently there are no BDMs that perform as well as LDPE clear films. Clear films require UV stabilization to retain their mechanical properties while in use, and current UV stabilizers are substances that will present an ecotoxicity hazard if left in the soil.[158]

Soil solarisation is another area where work has been undertaken to explore substituting conventional plastics with BDAPs. Typically, plastic is laid on the ground for 1-2 months and used to amplify the sun's heat, warming the soil to a temperature such that soil borne pathogens cannot survive. Early tests with BDMs found that early degradation limited its usefulness in this application.[159]

It has been suggested that biodegradable materials could be substituted for conventional agri-plastic in fruit bush covers, seedling bags and fruit protection bags. These are still at the experimental stage though early trials indicate there is potential here for using biodegradable materials as similar improvements in fruit quality are gained when using BDMs compared with conventional agri-plastics.[160]

In livestock production, biodegradable silage wraps are being developed, but are not commercially available yet. Silage wraps require different performance features from mulch films as they need to be stronger and have a low water vapour transmission rate,

---

[157] Touchaleaume, F., Martin-Closas, L., Angellier-Coussy, H., Chevillard, A., Cesar, G., Gontard, N., and Gastaldi, E. (2016) Performance and environmental impact of biodegradable polymers as agricultural mulching films, *Chemosphere*, Vol.144, pp.433–439

[158] Personal Communication, Sara Guerrini, Novamont. Email received 06/05/20

[159] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

[160] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

and low oxygen permeability. Furthermore, the film needs to retain its integrity for 12 months or longer, before beginning to degrade. This is a design challenge, particularly in climates where rainfall is high. A study in 2015 demonstrated the potential of biodegradable materials to meet this need but concluded that existing materials are not yet performing as desired and more research is needed.[161] It is understood that a prototype of biodegradable silage film will soon be available on market.[162]

One argument against the substitution of conventional with biodegradable plastic in silage wrap is that, in comparison to mulch films, it is easier to remove the silage films and dispose of them away from the farm. They also are likely to be cleaner than mulch films when removed, as they have not been in direct contact with the soil, making them more suitable to recycling processes.[163] Furthermore, the end-of-life route for a biodegradable silage wrap is unclear as it is likely to be collected into large quantities that could either be tilled into the soil or composted on site. Neither practice is straight forward or practical in large volumes (tilling and reseeding for grasslands grown for silage would not take place every year either[164]) and would be difficult to provide specific standards that would guarantee biodegradation performance. The extra work involved in managing this would also likely negate one of the potential benefits for a farmer of reduced waste handling.

Mulch films are manufactured by blown film extrusion but novel forms of mulch film are being explored which could expand the range of potential applications. Spray-based mulches are applied in liquid form making them more suitable for use on crops in trays but they have not gone beyond the testing stage.[165] [166] Non-woven materials consist of a random orientation of fibres, which creates a fabric that is both lightweight and possesses great strength, yet being highly crystalline and is slower to degrade. These are not yet at the point of commercial viability as the balance between performance and biodegradability is still being refined.[167]

The remainder of this report focuses on the use of BDAPS for mulch films, as this is the main existing application that also has an accompanying standard for verification. Biodegradable materials have been developed, tested and used as mulch films for close

---

161 Borreani, G., and Tabacco, E. (2015) Bio-based biodegradable film to replace the standard polyethylene cover for silage conservation, *Journal of Dairy Science*, Vol.98, No.1, pp.386–394

162 Spanish Grower's webinar conducted for this project on 22nd April 2020

163 Interview with Sara Guerrini (Novamont) 13.03.20

164 Agriculture & Horticulture Development Board (2018) Grassland-reseeding-guide.pdf

165 Giaccone, M et al (2018) Biodegradable mulching spray for weed control in the cultivation of containerized ornamental shrubs

166 Malinconico, M., Immirzi, B., Santagata, G., Schettini, E., Vox, G., and Mugnozza, G.S. (2008) AN OVERVIEW ON INNOVATIVE BIODEGRADABLE MATERIALS FOR AGRICULTURAL APPLICATIONS, p.47

167 Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

to 20 years, so there is a good body of evidence to draw upon.[168] Other applications are discussed where examples exist.

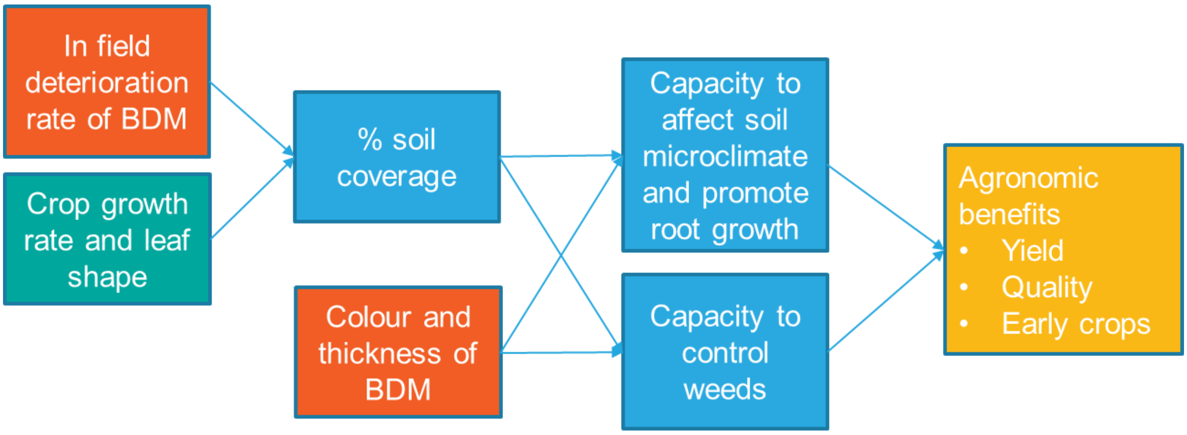
4.2 Comparing the Agronomic Benefits of Biodegradable and Conventional Plastic Mulch Films

This section seeks to explore the evidence for whether BDMs can be relied upon to produce agronomic results equivalent to those of LDPE films. This will be a major point of interest for growers and will inform the discussion on suitable applications for BDMs. There is a large body of work comparing the agronomic performance of BDMs with conventional mulch films across a range of crops and locations. This study has reviewed the academic literature and gathered the views of growers in Spain and Italy. A crop-by-crop summary of these findings can be found in the appendix A.4.1. In this section the main issues affecting BDM performance are discussed, and broad conclusions drawn.

4.2.1 Factors Affecting Agronomic Performance of BDMs

Agronomic performance is the economic benefit to growers from increased yields, quality or early production of crops. The primary factors affecting the performance of BDMs are the colour and thickness of the material and its rate of deterioration during use. (See Figure 4-1). The following sections describe how these factors interact.

Figure 4-1: Factors Affecting Agronomic Performance of BDMs



4.2.1.1 Deterioration of BDMs During Use

BDM's will deteriorate while in use from exposure to UV radiation, moisture and mechanical stress which can result in thinning and tearing. This deterioration will affect the proportion of the soil that is covered and hence the capacity of the film to produce the conditions that lead to agronomic benefits.

The mechanical properties of BDMs prior to use are found to be comparable to LDPE films in terms of strength in the parallel direction, but inferior in the transverse

[168] Novamont (2020) Position_Paper_Mulch film_Novamont_Apr20.pdf

direction.[169] This can lead to tearing when laying the material. Spanish growers in the webinars conducted for this report described that when laying a BDM, the machines used to apply them need to be set to work at a lower strength to apply less tension on the film to avoid tearing the film, and that this is a small adjustment to make.

Field trials show that the mechanical properties of BDMs change during use, in particular the elongation at break value drops within a week of exposure, increasing the chance of the material tearing.[170] It is therefore recommended in the European mulch film standard EN 17033 that growers plant over the mulch as soon after laying as possible. (The full specifications of EN 17033 are discussed in Section 4.4).

The functional lifespan of the mulch needs to match the growing pattern of the crop. For fast growing crops such as pumpkins the leaves are large so they will cover the mulch within 30 days. This means that if the BDM material starts to degrade after 30 days it will not affect its performance as the primary function of the mulch to protect young plants from weed competition will have been achieved. After this point the mulch may still play a role in disease prevention by keeping the plant and fruit separated from direct contact with the soil.

Deterioration of BDMs from early degradation of the material has been reported to increase growers' resistance to using BDMs.[171] However, growers in Spain who have been using BDMs for many years report that although early degradation occurs it does not affect performance unduly.[172] This observation is supported by several studies which report that early degradation did not affect functionality.[173] A Spanish study with pepper plants concluded that a visual assessment of deterioration overestimates the loss of functionality of mulches in comparison to more objective measurements of the deterioration rate such as measurements of weight loss over time.[174] This suggests that growers may be seeing what appears to be a highly weathered mulch but they may be incorrectly assuming that the mulch is ineffective.

The evidence shows that BDMs are more likely to tear during use than LDPE films, particularly in the transverse direction, but this visual deterioration does not equate to a

[169] Briassoulis, D. (2006) Mechanical behaviour of biodegradable agricultural films under real field conditions, *Polymer Degradation and Stability*, Vol.91, No.6, pp.1256–1272

[170] Scarascia-Mugnozza G, Schettini E, Vox G et al (2006) Mechanical properties decay and morphological behaviour of biodegradable films for agricultural mulching in real scale experiment. Polym Degrad Stab 91:2801–2808

[171] Yamamoto-Tamura, K., Hiradate, S., Watanabe, T., Koitabashi, M., Sameshima-Yamashita, Y., Yarimizu, T., and Kitamoto, H. (2015) Contribution of soil esterase to biodegradation of aliphatic polyester agricultural mulch film in cultivated soils, *AMB Express*, Vol.5, No.1, p.10

[172] Personal Communication with farmer's cooperative of Navarra

[173] Andrade, C., Palha, M., and Duarte, E. (2014) Biodegradable mulch films performance for autumn-winter strawberry production, *Journal of Berry Research*, Vol.4, pp.193–202

[174] Moreno, M.M., González-Mora, S., Villena, J., Campos, J.A., and Moreno, C. (2017) Deterioration pattern of six biodegradable, potentially low-environmental impact mulches in field conditions, *Journal of Environmental Management*, Vol.200, pp.490–501

significant loss of performance, and the agronomic benefits are still comparable to LDPE. [175] Choosing the right thickness of BDM for the crop will minimise issues with early degradation, and this is usually done by those who market BDMs to farmers to ensure they get the best product. The examples outlined show that in order to get the best performance from a BDM a degree of learning and adjustment is needed on the part of the grower, but this is not seen as a significant obstacle in practice.

4.2.1.2 Colour of BDMs and Performance

Conventional films are available in a range of colours (e.g. black, silver, yellow, photo-reflective, brown and red) and each has a specialised application depending on how the film absorbs and transmits solar radiation. Currently, BDMs are only available in three colours; black, cream, and green. Black BDMs perform similarly to LDPE black films. Green films are the most expensive of the three and selectively absorb infrared radiation allowing for soil warming at an intermediate level between clear and black. The cream films are closest to transparent films in function but degrade very quickly as they are weakened by exposure to UV radiation.[176] To avoid this, clear films require the addition of UV stabilizers but it is proving difficult to find biodegradable pigments that do not include metals (which may be toxic once the base material has degraded).

Growers who rely on the specialised functionality of coloured mulches may face a greater loss of functionality if they substitute these for BDMs with limited colour options.

4.2.1.3 Climate and BDM Performance

Climate affects which crops predominate in a region and this in turn affects the suitability of a location for the use of BDMs. Most of the studies comparing agronomic performance of BDMs have taken place in Spain, Italy, Portugal, the US and China where BDMs are widely used. There is a relative lack of studies exploring how BDMs perform in northern European climates and whether growers in these climates can expect the same benefits from BDMs as with LDPE films.

In northern latitudes the increased rainfall and groundwater levels could trigger earlier biodegradation of BDMs compared with drier southern latitudes. Hail and other weather events such as strong winds will also mechanically stress a film, increasing the risk of tearing. Italian growers in the webinar held for this report claim that hail events do not cause early degradation of BDMs when crop cycles are short (From April to October), although thicker BDMs are still recommended in places with these type of weather

---

[175] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

[176] Vox, G., Schettini, E., and Scarascia-Mugnozza, G. (2005) RADIOMETRIC PROPERTIES OF BIODEGRADABLE FILMS FOR HORTICULTURAL PROTECTED CULTIVATION, *Acta Horticulturae*, No.691, pp.575–582

events. In Europe the number of hail events is highest in mountainous areas and pre-Alpine regions.[177]

In southern latitudes the climatic stresses are different, but can also affect the agronomic performance of BDMs. Altering soil temperature is a key way in which BDMs affect the growth of crops and the need for this differs markedly across the climatic regions of Europe. Solar radiation levels vary across Europe and where direct solar radiation is predominant (e.g. southern Europe), a dark mulch will absorb more heat and in turn heat the soil and air more. If soil temperatures get too high this warming effect could be detrimental to crop growth and yield. In a Portuguese strawberry growing trial, lower yields were recorded for the crops grown under BDMs compared with PE mulch film and this was linked to the higher temperatures recorded on the BDM plots. [178] In central Europe, diffuse radiation is more prevalent and the warming effect will be reduced thus potentially limiting the agronomic benefits of using a mulch.

Overall, although the agronomic performance of BDMs is likely to be different for growers in different regions of Europe because of climatic factors, these limitations can be overcome by choosing an appropriate material and thickness of BDM. BDMs s can perform comparably to conventional films in most climates, though the greatest limitation on BDM usage currently is the lack of variation in colour range that growers are used to with conventional films. Climate factors are also relevant when looking at the overall biodegradation rate of BDMs in soil, and hence the possibility of accumulation of material.[179]This is covered in Section 4.3.1.2.

4.2.2 Suitability of Different Crops for Use with BDMs

Testing of BDMs with different crops has largely shown that with the right mulch, growers can expect similar yields to conventional mulches.[180] There are also three general categories of crops:

- **Short cycle:** growing and harvesting 3-6 months
- **Long cycle:** growing and harvesting 6-12 months
- **Perennial:** Lasting over two years and continuing to fruit

[177] EEA (2017) hail events.pdf

[178] Andrade, C., Palha, M., and Duarte, E. (2014) Biodegradable mulch films performance for autumn-winter strawberry production, *Journal of Berry Research*, Vol.4, pp.193–202

[179] Sintim, H.Y., Bary, A.I., Hayes, D.G., et al. (2020) In situ degradation of biodegradable plastic mulch films in compost and agricultural soils, *Science of The Total Environment*, Vol.727, p.138668

[180] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

Each category requires different film specification due to the different length of time required for performance. Appendix A.4.1 details the research on this crop by crop with the key points summarised in the following section.

4.2.2.1 Short Cycle Crops

BDMs lend themselves to short cycle crops as their protective properties are only required for a few months before the plant is harvested and the film can be tilled into the soil. This is where the majority of the usage takes place currently.

These include tomatoes, peppers, aubergines, lettuce, melons, pumpkins, courgettes and cucumbers; all of which have been tested and report similar yields compared with conventional plastic mulch.

Tomatoes grown for use in tins have been widely using BDMs for over 10 years. In the Navarra region of Spain 80% of the 2,000 hectares of processing tomatoes currently use BDMs. The reason given for this is to allow the mechanical harvesting of this crop that is not possible when LDPE films are used as fragments of LDPE films were contaminating the fields. [181] This is another example of how the needs of a particular crop will affect the choice of BDM used.

Peppers and aubergines are a common crop for BDM use in Italy and Spain. However, the growth pattern of pepper plants (erect with thin leaves) increases the exposure of the BDM to environmental factors thus resulting in more degradation during use phase than with other crops such as tomatoes.[182]

A more recent application where mulch films are not typically used is rice, where young rice shoots struggle in competition with weeds. Traditional rice production floods the rice fields as a means of weed control (rice can grow when submerged, but the weeds cannot). Modern management also uses herbicides. By using BDMs it is possible to produce rice which is organic i.e. without the use of herbicides and pesticides. Water consumption is also reduced without the need to flood and the quantity of seed used can be reduced by up to 80%.[183] In the 2017-8 crop year over 500 ha of organic rice production in Piedmont, Italy was using BDMs. Novel technology using BDMs impregnated with rice seeds has also been developed which allows the seedlings to develop whilst the mulch film inhibits weed growth.

4.2.2.2 Long Cycle Crops

The main application for long cycle crops is for strawberries, both inside and outside of greenhouses. Although several studies show BDMs producing equivalent yields to LDPE

---

[181] Novamont (2020) QAmulch_March_20.pdf
[182] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104
[183] Novamont (2020) QAmulch_March_20.pdf

mulches for strawberries, one study reported yields with BDM to be 20-37% lower than with LDPE film – this was thought to be caused by the BDM (over)warming the soil compared with LDPE mulch during the summer months.[184]

4.2.2.3 Perennial Crops

The use of mulch films for perennial crops to protect their initial growing stages is less widespread but young berry bushes and grapevines have been shown to benefit from mulching when they are transplanted. Because of the nature of the plants it is difficult to remove the film once the plant has grown larger, so if LDPE mulches are used, they can often be left to fragment or are time consuming to manually remove. BDMs appear to offer a 'solution', as the mulch can be left to degrade on the soil, although the time needed for full biodegradation in this case can be many years as if it is not fully incorporated into the soil.[185,186] The practice of regularly cultivating the soil around vines to reduce weed growth using an 'under-vine cultivator' can help to incorporate the material into the soil. This is used as an alternative to routinely spraying herbicides to suppress weeds or to mechanically removing weeds, but is not a widespread practice. Adopting the under-vine cultivator method of weed suppression at the same time as adopting BDMs would be necessary to achieve the correct conditions for biodegradation to take place.

Producers of BDMs argue that because BDMs can be left in the field after crop cultivation, they can be used on crops that are not normally mulched with LDPE films for technical or practical reasons such as asparagus, sweet corn (maize) and perennial fruits.[187] BDM producers have developed a black micro-perforated mulch for asparagus that aims to cover the seedbed but allow the young asparagus plants to break through.[188]

Whether the agronomic benefits of this justify the increased use of agricultural plastic in new applications needs to be considered carefully. It is also important to recognise that the current European biodegradable mulch film standard (EN 17033) is not generally applicable to perennial crops when there is an inability to incorporate into soil (more discussion of this in Section 4.4).

---

[184] Andrade, C., Palha, M., and Duarte, E. (2014) Biodegradable mulch films performance for autumn-winter strawberry production, *Journal of Berry Research*, Vol.4, pp.193–202

[185] Zhang, X., You, S. , Tian, Y., and Li, J. (2019) Comparison of plastic film, biodegradable paper and bio-based film mulching for summer tomato production: Soil properties, plant growth, fruit yield and fruit quality, *Scientia Horticulturae*, Vol.249, pp.38–48

[186] Touchaleaume, F., Martin-Closas, L., Angellier-Coussy, H., Chevillard, A., Cesar, G., Gontard, N., and Gastaldi, E. (2016) Performance and environmental impact of biodegradable polymers as agricultural mulching films, *Chemosphere*, Vol.144, pp.433–439

[187] Novamont (2020) Position_Paper_Mulch film_Novamont_Apr20.pdf

[188] Novamont (2020) QAmulch_March_20.pdf

4.2.2.4 Use of BDMs in Organic Farming

The use of BDMs in organic farming is an area where US practice differs from current practice in the EU. In the USA the National Organic Program added bio-based BDMs to their list of allowable substances in 2017 with the condition that 100% of the product is made from bio-based sources. Commercially available BDMs are typically around 25% bio-based so are effectively excluded from use on organic farms with this criterion. They are also rejected on the grounds that genetically modified organisms are often used to economically produce the biopolymers, and this is an excluded method for organic agriculture.[189]

In contrast, in Italy, BDMs are promoted as a means of supporting organic agriculture where herbicides are prohibited in organic farming systems. An Italian produced BDM has been developed that passes the AIAB (Italian Organic Farming Association) Technical Means specification, by having a "very high content of renewable components in the material used for the film" and using natural, renewable Non-GMO (genetically modified organism) sources, though the exact details of this are unknown.[190] A Spanish study comparing five BDMs also concluded that "the commercial and experimental tested films are adequate for mulching in organic farming systems" but they lack any evidence for this claim other than the fact that they used soil from an organic farm in which to test the biodegradation of the BDMs.[191]

The Italian Organic Farming Association (AIAB), together with Novamont and the Italian inspection body Bioagricert, have developed guidance that aims to ensure that BDMs are compatible with organic farming principles. The requirements are that in addition to being certified according to standard EN 17033, the materials should not contain GMO's and must meet certain requirements in terms of the renewable content in the raw materials. [192] No other country has replicated this, although if the defining feature of organic agriculture is that it avoids the use of synthetic herbicides and pesticides, then BDM use would be consistent with this, particularly if any bio-based content is derived from non-GMO sources.

4.2.3 Conclusions on the Agronomic Benefits of BDMS

The evidence reviewed has shown that:

- Certain **short cycle** crops are well suited to BDM use, and some of these demonstrate a good track record of agronomic performance;
- The colour and thickness of the material are key variables that affect agronomic performance and need to be selected to suit the application; This is done in

[189] https://bioplasticsnews.com/2020/04/09/biodegradable-plastic-mulch-berry-growers/
[190] Novamont (2020) QAmulch_March_20.pdf
[191] Barragán, D.H., Pelacho, A.M., and Martin-Closas, Ll. (2016) Degradation of agricultural biodegradable plastics in the soil under laboratory conditions, *Soil Research*, Vol.54, No.2, p.216
[192] Federbio (2020) Agronomic report on the use of biodegradable plastic

practice by the retailers of BDMs who guide growers to the product most suited for their crop and location.
- In order to get the best performance from a BDM a degree of learning and adjustment is needed on the part of the grower.

Therefore, similar agronomic benefits can be achieved using BDMs when the correct BDM is chosen for the particular crop and location, and this is combined with practice handling the material.

However, there are still limitations:

- The early degradation of BDMs can present a barrier to the increased uptake of these where growers assume that the visual deterioration translates into loss of function. Overall, deterioration during use of BDMs does not significantly affect the agronomic benefits of BDMs compared to LDPE.
- The variety in colour and the performance range that LDPE films offer cannot currently be matched by BDMs. Some growers who rely on specialised mulches will not be able to find a direct BDM equivalent.
- Climate could affect BDM performance, but there is a research gap in evaluating the agronomic performance of BDMs in northern European countries.
- Novel applications for BDM use on crops which are not normally mulched needs to be evaluated carefully before deemed suitable.

4.3 Assessing the Environmental Risks of Using BDMs

Whilst it is evident that residues of conventional plastics can cause environmental harm it is also important to investigate these same pathways for biodegradable plastics. These are:

1) Impacts on soil ecosystem whilst in use as a mulch.
2) Impacts on soil ecosystem after tilling into soil during biodegradation phase.
3) If the BDMs are not properly tilled into the soil there are issues with undegraded fragments remaining on the ground, and possibly leaking into waterways.

The effects of BDM mulch use on soil health indicators *during the use phase* are found to be similar to those of conventional films whilst the film remains intact.[193,194,195,196] There

[193] Saglam, M., Sintim, H.Y., Bary, A.I., Miles, C.A., Ghimire, S., Inglis, D.A., and Flury, M. (2017) Modeling the effect of biodegradable paper and plastic mulch on soil moisture dynamics, *Agricultural Water Management*, Vol.193, pp.240–250

[194] Chen, N., Li, X., Šimůnek, J., Shi, H., Ding, Z., and Zhang, Y. (2020) The effects of biodegradable and plastic film mulching on nitrogen uptake, distribution, and leaching in a drip-irrigated sandy field, *Agriculture, Ecosystems & Environment*, Vol.292, p.106817

[195] Bandopadhyay, S., Martin-Closas, L., Pelacho, A.M., and DeBruyn, J.M. (2018) Biodegradable Plastic Mulch Films: Impacts on Soil Microbial Communities and Ecosystem Functions, *Frontiers in Microbiology*, Vol.9

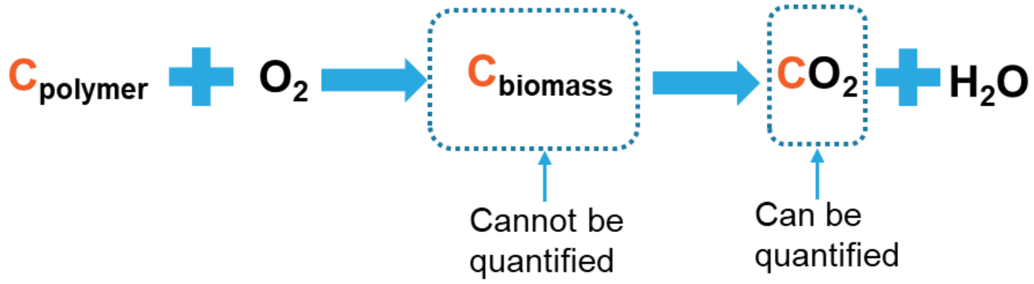
[196] Sintim, H.Y., Bandopadhyay, S., English, M.E., et al. (2019) Impacts of biodegradable plastic mulches on soil health, *Agriculture, Ecosystems & Environment*, Vol.273, pp.36–49

is no evidence to show that the effects of BDMs during use are likely to be detrimental to soil health, equally there is no evidence that shows BDMs have a positive impact on soil health above those that LDPE films also bring. The second issue will be explored in the following section, followed by an analysis of whether the existing standards are sufficient to keep these risks at an acceptable level.

4.3.1 The End-of-Life Biodegradation of BDMs

Biodegradation is the process in which a material is assimilated by microorganisms; bacteria and fungi. The aerobic process shown in the simplified equation below (Figure 4-2) shows how the microorganisms use oxygen to metabolise (biodegrade) the carbon in the polymer which is then mineralised into CO_2 and water. The microorganisms secrete enzymes which break down (cleave) the polymer chains to a size which makes them bioavailable. This biodegradation process takes place on the surface as the enzymes cannot penetrate the polymer which means that the carbon in the core of the plastic is unavailable until the outer is metabolised. This is the primary reason why thicker material biodegrades slower. Different soil conditions will also lead to fast or slower biodegradation based on, most critically the, presence of microorganisms and the temperature, but also affected by moisture content, oxygen availability, and pH value.

Figure 4-2: The Biodegradation Process



Source: Adapted from Chinaglia et al[197]

The way to gauge the progress of this process is to measure the consumption of oxygen or the production of CO_2. There is yet to be developed a reliable method to measure the transfer of carbon into biomass although this has recently been achieved on a small scale by labelling the carbon in the polymer and tracking it through the process.[198] Laboratory studies calculate that the amount of carbon used for biomass production depends on the material and varies between 10% and 40%.[199] This means that a measurement of the

[197] Chinaglia, S., Tosin, M., and Degli-Innocenti, F. (2018) Biodegradation rate of biodegradable plastics at molecular level, *Polymer Degradation and Stability*, Vol.147, pp.237–244

[198] Zumstein et al. (2018) *Biodegradation of synthetic polymers in soils: Tracking carbon into CO2 and microbial biomass,* Sci. Adv. 2018;4: eaas9024

[199] OWS (2016) Expert Statement: (Bio)degradable Mulching Films

available carbon that is converted to CO_2 may be less than 100% but ‘complete’ biodegradation has still occurred. [200] [201]

Biodegradation in the field cannot be directly measured as evolved carbon as it is in the laboratory, instead it can be measured as weight loss over time, or qualitatively through a visual assessment of deterioration. In the field ‘complete’ biodegradation should mean that there are no fragments of material left in the soil but variation in sampling and measuring techniques mean that this is difficult to confirm. A recent laboratory study has clearly shown that for biodegradable mulch films that pass the standard EN17033, the qualitative assessment of physical degradation is reliable as an indicator that mineralisation of the carbon into biomass has occurred. This is important as some materials on the market breakdown physically, but do not ultimately biodegrade, so fragments of microplastics remain in the soil negatively affecting soil health.[202]

Many studies place the mulch film in a mesh bag before burial which allows the easy extraction of the film from the soil, but is criticised as it is suspected that the mesh bag interferes with normal microbial activity so biodegradation rates reported may be slower than for samples left in the open field. Other sampling methods include using a golf hole cutter,[203] or taking larger random samples of the field which are sieved to extract fragments of the mulch[204]. In all these cases micro and nano particles are likely to be missed when sieving the soil to capture fragments for weighing, suggesting that measurements may be overestimating the weight loss and rate of biodegradation. A typical size for the sieve used has holes of 2.6mm.

The overall time taken for a BDM to fully biodegrade is important as it affects whether there is likely to be an accumulation of material residue in the soil if BDMs are used annually. Figure 4-3 shows that the main factors affecting biodegradation in soil are climate, material variables, and soil variables. These will be discussed in turn.

[200] OWS (2016) Expert Statement: (Bio)degradable Mulching Films

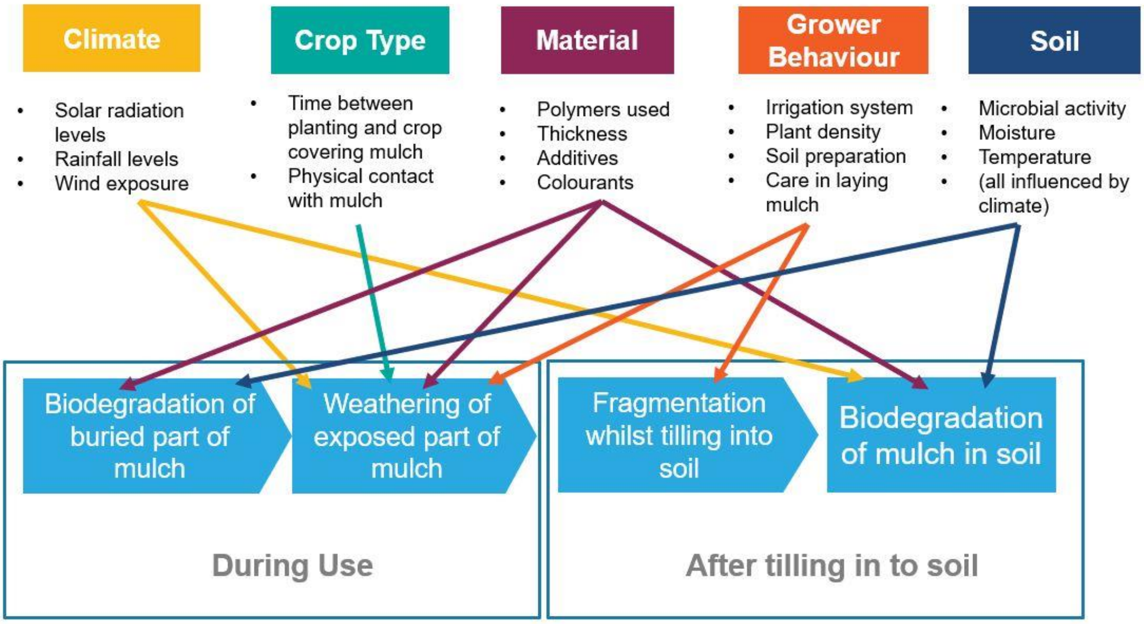
[201] Bettas Ardisson, G., Tosin, M., Barbale, M., and Degli-Innocenti, F. (2014) Biodegradation of plastics in soil and effects on nitrification activity. A laboratory approach, *Frontiers in Microbiology*, Vol.5

[202] Tosin, M., Barbale, M., Chinaglia, S., and Degli-Innocenti, F. (2020) Disintegration and mineralization of mulch films and leaf litter in soil, *Polymer Degradation and Stability*, p.109309

[203] Cowan, J.S., D.A. Inglis, and C.A. Miles. 2013. Deterioration of three potentially biodegradable plastic mulches before and after soil incorporation in a broccoli field production system in northwestern Washington. HortTechnology 23:849-858.

[204] Ghimire, S., Flury, M., Scheenstra, E.J., and Miles, C.A. (2020) Sampling and degradation of biodegradable plastic and paper mulches in field after tillage incorporation, *Science of The Total Environment*, Vol.703, p.135577

Figure 4-3: Factors Affecting Time Until Full Biodegradation of BDMs



4.3.1.1 Material Factors Affecting Biodegradation Rate of BDMs

All potentially biodegradable mulches are made from polyesters which have monomers linked by ester bonds that can be broken down through the actions of enzymes released by microbes. Table 4-1 shows the estimated comparative rate of biodegradation of the main polymer types used in BDMs using a qualitative estimation by Brodhagen et al. [205] These descriptive labels are necessary as complete comparisons between materials are not available. Comparisons also provide no indication of whether each of the materials is suitable for use as a BDAP as different rates of biodegradation may be suitable for different applications e.g. lower rates may be more desirable in warmer climates and faster rates in colder climates to provide equivalent performance. The exception to this is PLA, that will not biodegrade in ambient temperatures unless blended with other more readily degradable polymers and therefore is not used in BDMs on its own.

---

[205] Brodhagen, M., Peyron, M., Miles, C., and Inglis, D.A. (2015) Biodegradable plastic agricultural mulches and key features of microbial degradation, *Applied Microbiology and Biotechnology*, Vol.99, No.3, pp.1039–1056

Table 4-1: Comparative Biodegradation Rates of Main Polymer Types

Polymer	Estimated comparative rate of biodegradation in soil	Additional Information
Starch	High[1]	
Cellulose	Moderately High[1]	Provided only as a reference – all biodegradation testing uses cellulose as a control substance
PHA	Moderate[1]	Most notably PHB and PHV are the main commercially available types
PBSA	Moderate[2]	There is evidence to suggest PBSA has slightly improved biodegradability over PBS
PBS	Low, moderate[1]	
PBAT	Low, moderate[1]	Low on its own, but blended with starch, can be improved – PBAT/starch is used by Novamont as Mater-bi and PBAT/PLA is used by BASF under Ecovio
PLA	Low[1]	PLA will not biodegrade in soil on its own at the ambient temperatures found in soil, but it is often blended with other polymers (PBAT/PHA) to achieve improved biodegradation and physical properties.

Notes:

1. *Categorisation given by Brodhagen et al 2015.*
2. *PBSA categorising estimated based on reported improved biodegradation compared with PBS*[206]

Starch has a high biodegradation rate and therefore blending it with other less degradable polymers increases their overall biodegradation rate, while also combining and enhancing the physical properties of the polymers—starch-based films on their own generally struggle to meet the strength requirements for mulch films.[207] For this reason, PBAT/starch blends are the most common form of material used in BDMs. Importantly,

---

[206] Puchalski, M., Szparaga, G., Biela, T., Gutowska, A., Sztajnowski, S., and Krucińska, I. (2018) Molecular and Supramolecular Changes in Polybutylene Succinate (PBS) and Polybutylene Succinate Adipate (PBSA) Copolymer during Degradation in Various Environmental Conditions, *Polymers*, Vol.10, No.3

[207] Sun, T., Li, G., Ning, T.-Y., Zhang, Z.-M., Mi, Q.-H., and Lal, R. (2018) Suitability of mulching with biodegradable film to moderate soil temperature and moisture and to increase photosynthesis and yield in peanut, *Agricultural Water Management*, Vol.208, pp.214–223

regardless of the polymer that is used, a thicker material will degrade slower than a thinner one within the same polymer group.[208]

One study compared a range of different BDMs and found that 65% of the variability in degradation rate after tilling was accounted for by differences in the materials. Only 10% of the variation in in-soil degradation could be explained by location or crop seasonal factors.[209] Differences in biodegradation rates of BDMs in the same location can largely be explained by the polymer constituents and thickness of the material.

4.3.1.2 Effect of Climate on Biodegradation Rate of BDMs

Laboratory tests for biodegradation follow a protocol that tests materials within the temperature range of between 20 and 28°C which is chosen to optimise the test for biodegradation (See Section 4.4). The range of field soil temperatures in Europe across the seasons is much wider than this and can slow the biodegradation of BDMs as fungal and bacterial activity is known to slow down as temperatures lower. The growth rate of these microorganism populations halves between 20°C and 10°C.[210] This phenomenon is known as the 'rule of 10' where the temperature coefficient (Q_{10}) is the factor by which the activity rate doubles when the temperature is raised by 10°C in chemical reactions, and the same is also often observed for biodegradation activity.[211]

A recent study conducted by Novamont tested their own starch blend polymer in soil which showed a mineralization rate of just under 30% at 15°C compared with just under 80% at 28°C within one year.[212] A regression model was developed as part of the study to estimate the time to full mineralisation of this material at any soil temperature[213] and Italian average soil temperatures of 14°C were used as an example. This estimated that it would take 82 days to mineralise a 15 µm thick film. Using the author's equation shows that for a 10°C average temperature, the same material would take 150 days and extrapolating further, a mulch film of 25 µm thickness could take 251 days. Countries at latitudes of 56°N and higher (Scandinavia, Denmark, Northern England and the Baltics),

[208] Wang, Z., Wu, Q., Fan, B., et al. (2019) Testing biodegradable films as alternatives to plastic films in enhancing cotton (Gossypium hirsutum L.) yield under mulched drip irrigation, *Soil and Tillage Research*, Vol.192, pp.196–205

[209] Martín-Closas, L., Costa, J., Cirujeda, A., et al. (2016) Above-soil and in-soil degradation of oxo- and bio-degradable mulches: a qualitative approach, *Soil Research*, Vol.54, No.2, p.225

[210] Pietikäinen, J., Pettersson, M., and Bååth, E. (2005) Comparison of temperature effects on soil respiration and bacterial and fungal growth rates, *FEMS Microbiology Ecology*, Vol.52, No.1, pp.49–58

[211] Nottingham, A.T., Bååth, E., Reischke, S., Salinas, N., and Meir, P. (2019) Adaptation of soil microbial growth to temperature: Using a tropical elevation gradient to predict future changes, *Global Change Biology*, Vol.25, No.3, pp.827–838

[212] Pischedda, A., Tosin, M., and Degli-Innocenti, F. (2019) Biodegradation of plastics in soil: The effect of temperature, *Polymer Degradation and Stability*, Vol.170, p.109017

[213] The authors state that the validity of the model for temperatures outside the tested range (15-28 °C) is questionable, but a few degrees either side may still be valid.

have average soil temperatures at around 10°C[214] suggesting that in these locations the time needed for full biodegradation of BDMs will be nearly double of that required in the southern regions. Table 4-2 shows a range of soil biodegradation rates that would be expected under *lab conditions* for various thicknesses and temperatures.

Table 4-2: Soil Biodegradation Regression Modelling

Soil Temperature (ºC)	Time to Biodegrade (days)		
	15um	25um	35um
5	319	532	745
10	150	251	351
12	111	186	260
15	71	118	165

Soil moisture levels are also a significant climatic factor with a minimum level of moisture needed to start the biodegradation process. Water is necessary for the chemical breakdown of material through hydrolyzation of ester bonds, which allows the microorganisms to penetrate into the material. It has been observed that in climates where rainfall levels are low the soil can become so dry that biodegradation is inhibited.[215] There is no evidence to show how higher rainfall levels of northern European climatic zones will affect the total duration needed for full biodegradation of BDMs but it has been shown to trigger early biodegradation in the field. To avoid triggering early degradation due to rainfall, thicker BDMs are potentially better suited to these regions, however the lower temperatures also found will slow the overall time for degradation – it is therefore important for the film suppliers to understand the local climatic conditions and specify a product that will degrade at the appropriate time. This can often involve trialling in one field initially in order to determine whether the correct film has been chosen and to help educate the farmer on the ways it should be handled and what to expect. Anecdotally, BASF have found during trials with their films that early degradation is often the biggest problem, particularly when subjected to unseasonal adverse weather.[216] This may become more of a challenge as climate change increases the likelihood of these types of event.

---

[214] Andersson, K., Nielsen, S., Thørring, H., et al. (2012) Parametric improvement for the ingestion dose module of the European ARGOS and RODOS decision support systems, *Radioprotection*, Vol.46, pp.S223–S228

[215] Costa, R., Saraiva, A., Carvalho, L., and Duarte, E. (2014) The use of biodegradable mulch films on strawberry crop in Portugal, *Scientia Horticulturae*, Vol.173, pp.65–70

[216] Interview with BASF

4.3.1.3 Effect of Soil Factors on Biodegradation Rate of BDMs

Biodegradation is entirely dependent on the health of microorganism populations. Fungi have been shown to be particularly important factors accelerating the biodegradation of polymers used in BDMs, with some studies suggesting that fungi populations are more critical than bacterial activity.[217] This has been observed for PBSA,[218] PHVB,[219] and PBAT[220] when tested in laboratory conditions.

A US study tested four BDMs in three different locations which differed in soil type, elevation, and annual precipitation though ambient temperature ranges were all within those similar of a northern European climate.[221] The authors found that at a given location the differences in biodegradation rates could be explained by the material factors (polymers used); differences in biodegradation rate of the same material at different locations was not entirely explained by differences in climate factors. After two years, the percent of mulch area remaining was 2% at one site, but 43% and 89% at the other sites. Fungi population levels were found to be very high in the location where biodegradation was the highest but the authors conclude that the variation is a result of the combined soil factors with biotic variables in what they describe as "*complex web of interactive forces*."[222]

In conclusion, the time required for complete biodegradation of a BDM in soil can vary significantly in the field from the time indicated in laboratory tests for particular materials. Climatic factors can explain some of the observed variation in field biodegradation rates but variation in soil factors can also significantly affect these rates and are less well understood.

---

[217] Yamamoto-Tamura, K., Hiradate, S., Watanabe, T., Koitabashi, M., Sameshima-Yamashita, Y., Yarimizu, T., and Kitamoto, H. (2015) Contribution of soil esterase to biodegradation of aliphatic polyester agricultural mulch film in cultivated soils, *AMB Express*, Vol.5, No.1, p.10

[218] Yamamoto-Tamura, K., Hiradate, S., Watanabe, T., Koitabashi, M., Sameshima-Yamashita, Y., Yarimizu, T., and Kitamoto, H. (2015) Contribution of soil esterase to biodegradation of aliphatic polyester agricultural mulch film in cultivated soils, *AMB Express*, Vol.5, No.1, p.10

[219] Sang BI, Hori K, Tanji Y, Unno H (2002) Fungal contribution to in situ biodegradation of poly(3-hydroxybutyrate-co-3-hydroxyvalerate) film in soil. Appl Microbiol Biotechnol 58:241–247, doi:10.1007/s00253-001-0884-5

[220] Kasuya K, Ishii N, Inoue Y, Yazawa K, Tagaya T, Yotsumoto T, Kazahaya J, Nagai D (2009) Characterization of a mesophilic aliphatic-aromatic copolyester degrading fungus. Polym Degrad Stab 94:1190–1196, doi:10.1016/j.polymdegradstab.2009.04.013

[221] Li, C., Moore-Kucera, J., Miles, C., Leonas, K., Lee, J., Corbin, A., and Inglis, D. (2014) Degradation of Potentially Biodegradable Plastic Mulch Films at Three Diverse U.S. Locations, *Agroecology and Sustainable Food Systems*, Vol.38, No.8, pp.861–889

[222] Li, C., Moore-Kucera, J., Miles, C., Leonas, K., Lee, J., Corbin, A., and Inglis, D. (2014) Degradation of Potentially Biodegradable Plastic Mulch Films at Three Diverse U.S. Locations, *Agroecology and Sustainable Food Systems*, Vol.38, No.8, pp.861–889

4.3.2 Comparative Accumulation of Biodegradable and Conventional Plastic in the Soil

Laboratory studies have shown that BDMs ranging in thickness between 14-44µm can reach 95% weight loss after 180 days.[223] Similar results have been recorded in field studies; an Italian study from 2006 found that only 4% of the BDM remained into the soil one year after the mulch tillage.[224] The BDM in this study was 25-45µm which is thicker than average BDMs which would suggest that thinner BDMs would perform even better. A recent laboratory study found that the rate of mineralisation of two BDM samples was spread evenly across the full year with 50% occurring in the final six months of the year. These samples were incubated at a constant temperature of 28 degrees, so in the field this process is likely to take more than a year.[225]

Indeed, several field studies report that a significant proportion of the BDM material can still be found in soil a year after tilling.[226,227] A Spanish study of six BDMs recorded that 200 days after tilling into the soil, the weight of the mulch residues in the soil had decreased by 42% to 73%, suggesting that biodegradation is not complete within this time.[228] A Chinese study found that after 2 years, between 30% and 50% of the PBAT and PBSA BDMs material was still present. The authors concluded that the complete degradation of these films in the soil would take a few years, though average temperatures in this region are similar to Northern Europe (5-10^{o}C).[229]

There is only one study that has field tested the accumulation of BDMs in soil over a number of years of repeated mulch use in a way that attempts to replicate real-life

---

[223] Barragán, D.H., Pelacho, A.M., and Martin-Closas, Ll. (2016) Degradation of agricultural biodegradable plastics in the soil under laboratory conditions, *Soil Research*, Vol.54, No.2, p.216

[224] Scarascia-Mugnozza, G., Schettini, E., Vox, G., Malinconico, M., Immirzi, B., and Pagliara, S. (2006) Mechanical properties decay and morphological behaviour of biodegradable films for agricultural mulching in real scale experiment, *Polymer Degradation and Stability*, Vol.91, No.11, pp.2801–2808

[225] Tosin, M., Barbale, M., Chinaglia, S., and Degli-Innocenti, F. (2020) Disintegration and mineralization of mulch films and leaf litter in soil, *Polymer Degradation and Stability*, p.109309

[226] Li, C., Moore-Kucera, J., Miles, C., Leonas, K., Lee, J., Corbin, A., and Inglis, D. (2014) Degradation of Potentially Biodegradable Plastic Mulch Films at Three Diverse U.S. Locations, *Agroecology and Sustainable Food Systems*, Vol.38, No.8, pp.861–889

[227] Moreno, M.M., González-Mora, S., Villena, J., Campos, J.A., and Moreno, C. (2017) Deterioration pattern of six biodegradable, potentially low-environmental impact mulches in field conditions, *Journal of Environmental Management*, Vol.200, pp.490–501

[228] Moreno, M.M., González-Mora, S., Villena, J., Campos, J.A., and Moreno, C. (2017) Deterioration pattern of six biodegradable, potentially low-environmental impact mulches in field conditions, *Journal of Environmental Management*, Vol.200, pp.490–501

[229] Wang, Z., Wu, Q., Fan, B., et al. (2019) Testing biodegradable films as alternatives to plastic films in enhancing cotton (Gossypium hirsutum L.) yield under mulched drip irrigation, *Soil and Tillage Research*, Vol.192, pp.196–205

conditions.[230] This US study tested four BDMs over a four-year period.[231] Six months after tilling in the soil the average recovery of the BDMs was 50% (range 31% - 67%), and after 36 months around 40% of the cumulative material was still present in soil samples. The authors also noted that their sampling technique meant that fragments smaller than 2.36 mm would have passed through the sieve and not counted and therefore the film remaining in the soil would have been underestimated.

The results of this study can be used to contextualise and provide an indication of whether accumulation is likely and how this compares with conventional (PE) mulch films. Figure 4-4 shows the projected accumulation in soil per hectare over 15 years with a fallow year every two years. A description of the calculation method can be found in Appendix A.4.3. Two conventional film scenarios are shown with a 75% and 90% recovery rate to represent a worst and best case respectively. The threshold for negative impact of 240kg/hectare as identified in Section 3.4.1.1 is the point in which yields may be affected (although this point is far from certain currently). It takes 11 years for 75% field recovery to reach this point; a 90% recovery takes 26 years. In contrast, the BDM continually cycles below this line as the material is biodegraded. It should also be recognised that this threshold is only indicative and it is unknown whether a consistent soil concentration of BDMs at this level would also have the same yield impacts as conventional films. However, maintaining levels below this is still likely to be the best precautionary approach until longer term research is conducted to verify this.

This graph is also a simplification due to the fact that the BDMs will not biodegrade linearly, but accelerate from the point in which it is tilled into the soil and will speed up and slow down throughout the seasons, however it demonstrates that—based on the extrapolation from a narrow set of results— it is likely that the material will not significantly accumulate over time.

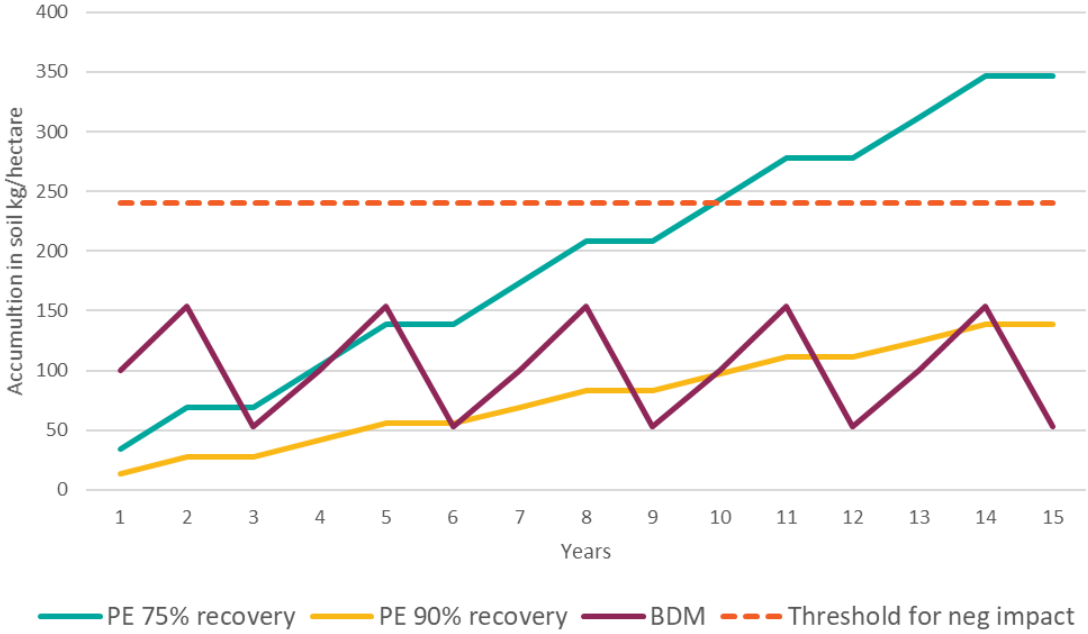
This scenario is based on the average annual soil temperature at the study location (Washington State, USA) of 12°C. According to the temperature regression model described in Section 4.3.1.2, based on lab tests, a 25 µm film at 12°C should biodegrade within 186 days. This is evidently not the case where residues appear to persist for up to three years after laying (2.5 years after tilling). This underlines the differences between lab and real-life testing where variations in microorganisms, moisture levels and temperature fluctuations all contribute to biodegradation speed. In reality, using annual average soil temperatures to model biodegradation is also likely to overestimate the speed.

[230] Ghimire, S., Flury, M., Scheenstra, E.J., and Miles, C.A. (2020) Sampling and degradation of biodegradable plastic and paper mulches in field after tillage incorporation, *Science of The Total Environment*, Vol.703, p.135577

[231] The four BDMS were: 1 PBAT based, 1 starch based, and 2 PLA based, one commercially available PBAT/PLA and one experimental PLA/PHA blend.

Figure 4-4: Comparison of Mulch Film Soil Accumulation

20µm thickness for BDM; 25µm thickness for conventional PE film



Nevertheless, using the data from both studies, an indication of potential accumulation relative to local temperature can be achieved. Figure 4-5 shows this at four annual average soil temperatures; 12ºC as studied in the US, 5ºC as found in far northern Europe 10ºC as found in central Europe, and 15ºC as found in southern Europe. The regression model indicates that it takes 35% longer to biodegrade between 12ºC and 10ºC which means that for at 25 µm film it takes four years rather than three; at 15ºC this is reduced to just over two years. At 5ºC this may be as much as eight years, although the uncertainty at these temperatures is high given how far this is outside of the actual temperatures tested for the development of the regression model.

Equally, 5ºC is a very low temperature at which to plant crops which is at the lower limit of the germination temperature of many vegetable types (typically 2-4ºC).[232] However, an average temperature of 5ºC for the year, would result from higher temperatures in the summer growing season months and potentially sub-freezing temperatures in the Winter. This means that this is still a viable average temperature to represent a growing scenario for regions North of the 56th parallel.

The results indicate that at lower temperatures with 25 µm film accumulation may begin to be high enough that negative impacts on crop yield could be possible, particularly if

[232] Balkan Ecology Project (2017) *Soil Temperature and Seed Germination*

no fallow year is practiced. However, specific field research would be required to verify this.

However, in reality, 25 µm is likely to be on the higher end of thicknesses used for BDM, particularly in cooler climates (a thinner film or a material with a higher rate of biodegradability is often used here), therefore Figure 4-6 shows the modelled results at 15 µm which is a more realistic usage thickness. This shows that anything but continual use of mulch films at 5°C is well below the negative impact threshold. Soil temperatures of 15°C are not shown on the graph as these are modelled to biodegrade fully within the first year.

It is worth noting that in the stakeholder engagement with growers in Spain and Italy, none of the growers who have been using BDMs for some years report issues with accumulation (as one might expect given the projection in Figure 4-5) although none have analysed soil samples to determine this empirically.

These indicative results based on interpreting the limited data available suggest that when using BDMs repeatedly there will always be some material in the soil during the biodegradation phase, but that this level is likely to stabilize. If a field is left a year without applying a BDM, any accumulated material should reduce close to zero in warmer climates, but still persist for longer at a low level in more temperate climates. **However, this analysis is based on limited existing long term data that is still inconsistent and does not provide the credibility required to determine firm conclusions. Nevertheless, it provides an indicator of the likely risk of accumulation which appears to be somewhat lower than that of conventional plastics unless close to 100% rates of field recovery of these conventional plastics are achieved.** What is also unknown is whether there could be any long-term effects from having these much lower concentrations of BDM in the soil over many years—the long term experience in Italy is cited by stakeholders as evidence for the lack of long term impact, but no data has been found or submitted that can verify this beyond reports based on the experience of growers.

Figure 4-5: Model of BDM Accumulation at Different Soil Temperatures - 25µm film thickness

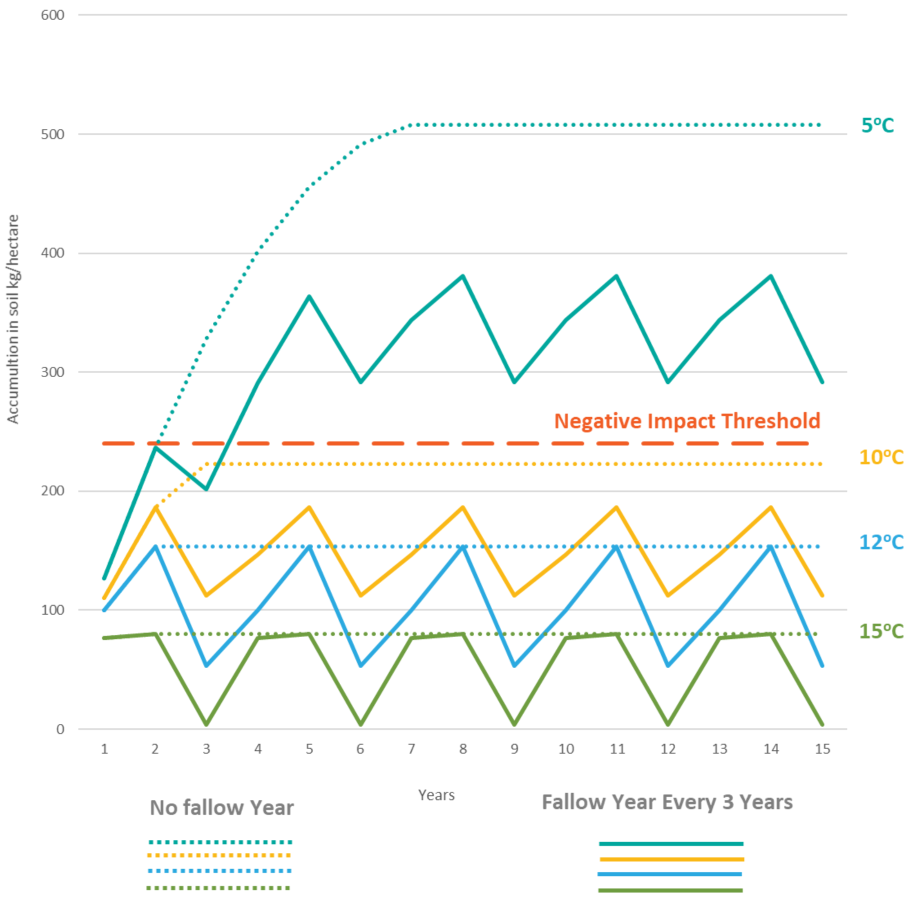
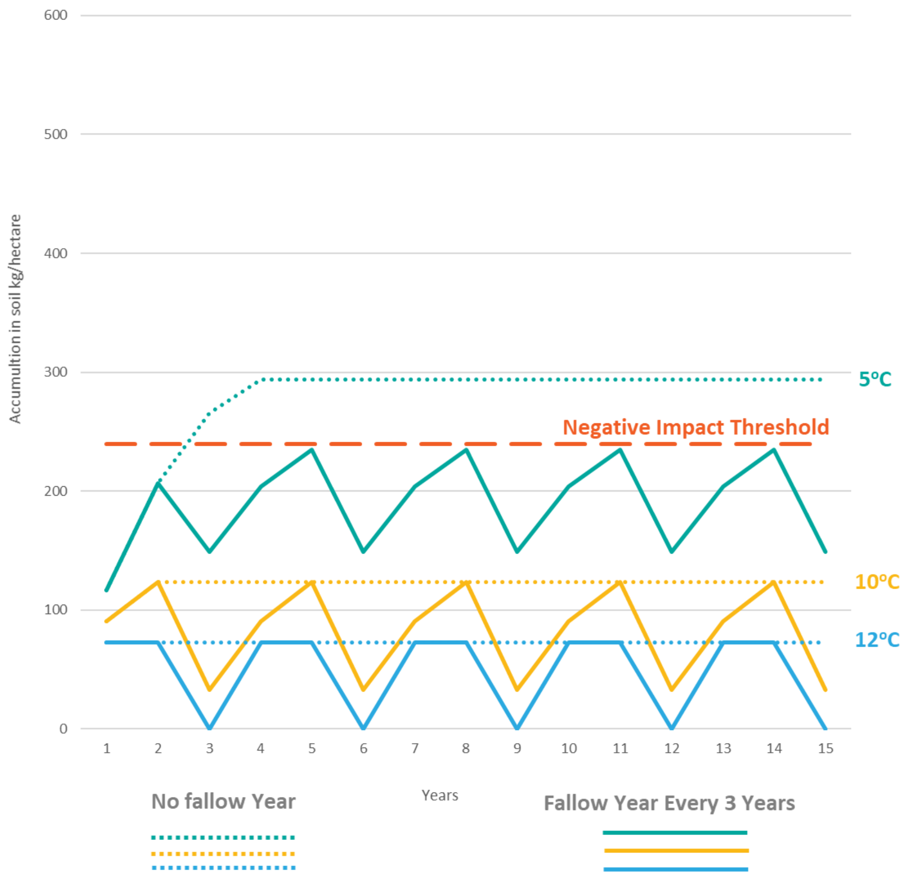


Figure 4-6: Model of BDM Accumulation at Different Soil Temperatures - 15µm film thickness



4.3.3 Environmental Impacts of Biodegradable and Conventional Agri-plastics

As well as the environmental risks associated with the use of agri-plastics if they are left in the open environment, it is also important to address their environmental performance during the whole lifecycle. This is because materials from different origins (e.g. bio- or fossil-based) and with different (technical) properties are used for biodegradable and conventional agri-plastics, and this affects the overall environmental performance of available alternatives. For instance, most biodegradable mulch films contain at least some bio-based material, i.e. material derived from biological source, where carbon taken up from the atmosphere is temporarily stored until full biodegradation[233] occurs. This is in contrast with conventional fossil-based films incorporating carbon that would otherwise be 'locked-up' underground. This means that the full carbon balance throughout the entire lifecycle should be carefully considered. However, comparative evaluations between biodegradable and conventional agri-plastics shall be carried out with caution, ensuring these rely on as much as possible transparent, consistent, reliable, and reproducible studies, based on common and harmonised methodological rules.

The JRC conducted a number of life cycle assessment (LCA) case studies for plastic products relying on alternative feedstocks (e.g. bio- and fossil-based feedstocks)[234], with the main aim of testing and illustrating the practical applicability of a method enabling as much as possible harmonised, consistent, and reproducible LCAs of plastic products. As such, they were not aimed at proving nor claiming the ultimate overall environmental superiority of one of the assessed products over the other ones, and results shall be interpreted in light of the assumptions performed and the limitations affecting the studies (as detailed in the case study report). For instance, in some cases the applied life cycle inventory data only approximated real processes (e.g. PBAT production or LDPE recycling). Moreover, according to common LCA practice, applied data reflected current (or recent past) production conditions, and hence they did not account for any potential process improvement or development that may take place in the future for more recent technologies (e.g. those used in the production of some bio-based polymers).

One of the case studies focused on mulch film, where the use of virgin LDPE, recycled LDPE, starch-based and PLA-based materials was evaluated for mulch film production. The starch- and PLA-based materials are blends of bio-based (starch, PLA) and fossil-

[233] With "full biodegradation" being intended as mineralisation into CO_2 (and possibly CH_4), metabolisation by soil microorganisms, and conversion into new soil biomass of the material and of any intermediate degradation compounds generated during biodegradation. Carbon incorporated into new soil biomass can then be further mineralised, until stable organic compounds (e.g. humic compounds) are formed, similarly to organic material applied on soil (e.g. compost or digestate). However, biodegradation pathways of (bio)-plastic materials in soil still have to be completely understood.

[234] Nessi S, Sinkko T, Bulgheroni C, et al. (2020) *Comparative Life-Cycle Assessment of Alternative Feedstock for Plastics Production - 10 LCA case studies*, Report for European Commission, June 2020

based plastics (PBAT) likely to represent Novamont's Mater-bi and BASF's Ecovio respectively (although the study does not explicitly name these products/brands). One of the common problems with biodegradable plastics is that they are often specific and proprietary formulations and it is therefore unclear whether their environmental impacts can be generalised in the same way as typical conventional polymers. The life cycle inventory data for particular products is generally not publicly available so making links between specific products on the market and the aggregated data this is available is difficult and may lead to unreliable results.

The following key assumptions were applied in the LCA study, especially regarding conventional non-biodegradable mulching film. These are important as they are likely to influence the results, but in some cases are different from the findings of the current report:

- LDPE mulch film is assumed to be 35 microns thick, which is reported in the study as the rounded average of the upper and lower values of thicknesses found on the market. This may be an even significant over estimation around typical current practices in EU as stakeholders have suggested the range to be generally 15-20 microns for most applications, with the thicker films used for specialist, long-term applications – this means taking the average of the upper and lower limit is unlikely to represent an average of sales. Furthermore this figure is 10-15 microns thicker than the minimum thickness recommended by EN 13655 for mulching film intended to be removed from soil after use (i.e. 20-25 microns, depending on the film colour). This is important, as the Standard was created to tackle the prevalence of thinner films and would be unnecessary if films were typically 35 microns or greater.
- The end-of-life scenario for LDPE film includes 20% mechanical recycling, 45% incineration and 35% landfilling. Additionally, a 90% field recovery rate and a soil contamination rate of collected film equal to 45% were assumed. These are all assumptions that are similar to the findings of the current report (See Section 2.5).
- For the recycling pathway, an initial sorting step similar to processes applied to mixed plastic waste from separate municipal collection is assumed. However, in reality mulch film collected from soil would be already segregated at source (See Section 3.1), and hence the assumption is partly conservative since no sorting would in principle be needed (and no additional impacts from this step should be accounted) although this assumption refers to only 18% of mulch film applied to soil and is hence likely to only marginally affect the overall results.
- The recycling process efficiency is assumed to be 84% on the actual plastic material input to recycling. If soil contamination (45%) is accounted, the overall recycling efficiency would be equal to nearly 46%, which is almost in line with the findings presented earlier in this report (i.e. around 35%, but for thinner film of 15-20 microns; see Section 3.2.3.1).
- The study assumes a 90% mineralisation rate for biodegradable mulch film left in soil after use, i.e. at the end of the biodegradation process 90% of organic carbon in the material is assumed to be converted into CO_2 (according with the minimum

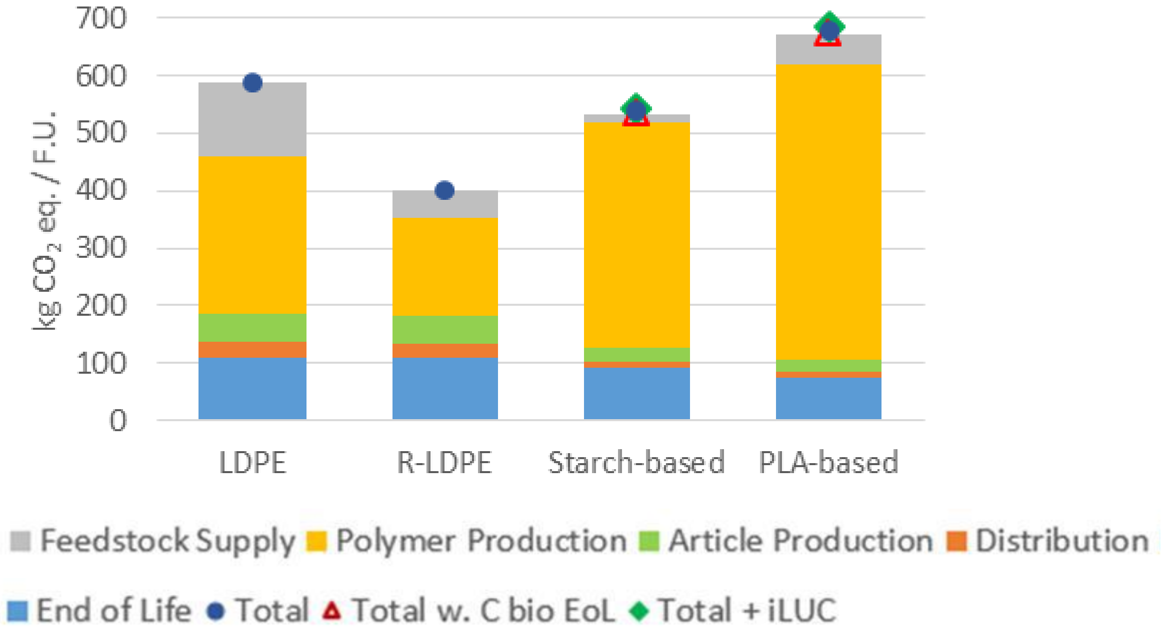
requirement from EN 17033 when testing aerobic biodegradability of mulching film), the rest being ultimately transferred into new soil biomass. As discussed in a previous report for the Commission on compostable plastic products[235], the 90% threshold chosen by most biodegradation standards refers to a lab scale test to prove inherent biodegradability, while this may not be achieved in reality as a higher proportion of the carbon becomes part of the biomass in the soil and less is converted into CO_2. Therefore, the 90% assumption can be considered a 'worst case' scenario with regard to GHG emissions, although there is currently no clear evidence on the actual fate of mulching film in real soil conditions (i.e. how much of the carbon is mineralised into CO_2 and H_2O, and how much is incorporated into new -stable- soil biomass).

Figure 4-7 shows as an example the results of the illustrative study on mulching film for the Climate Change impact category. Within the assumptions and limitations discussed above, mulching film made of 100% recycled LDPE (R-LDPE) was found to have the lowest impact for this category, i.e. 30% lower than virgin LDPE film and 25-40% than biodegradable films. It must be noted, however, that use of 100% recycled material for mulch film production is reported in the study to be likely not (yet) feasible at present, and hence represent an optimistic scenario. Moreover, recycled LDPE was not assumed to specifically derive from closed loop recycling of used mulch film (but from unspecified LDPE waste from municipal and industrial collection). Starch-based and PLA-based films are both within 10-15% of the impact from using virgin LDPE film, which can be considered a non-significant difference when interpreting LCA results. However, the assumption that the LDPE film has a thickness of 35 microns certainly has an impact on this result; reducing the thickness to 25 microns—i.e. a nearly 30% reduction—would reduce the mass of material and hence the overall impact by approximately 30%. This would give LDPE film an advantage over biodegradable alternatives under the assumptions and conditions of the study.

---

[235] Hann, S., Molteno, S., Hilton, M., and Favoino, E. (2020) *Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy*, Report for European Commission DG Environment, February 2020

Figure 4-7: Climate Change Potential Impact –LCA of Mulch Films



Source: JRC

Climate Change impacts have been calculated both excluding (default approach) and including the contribution of biogenic carbon taken up during biomass growth and not released after 100 years from End of Life (i.e. after mulch film use has ended). However, no significant differences were observed in the overall impact, since net emissions of biogenic CO_2 are close to neutral for the two biodegradable materials (i.e. what is taken up from the atmosphere is mostly emitted during biodegradation). If a larger proportion of organic carbon in the material was retained in the biomass of the soil (with no detrimental effects on its actual biodegradation), this may have a have an even considerable effect on the results in favour of biodegradable plastics, but at this time accurate tracking of the carbon during biodegradation is not possible.

Looking at the contribution of the different lifecycle stages, the Polymer Production was found to be the most relevant stage for all materials, with bio-based films showing a higher Climate Change impact during this stage compared to fossil-based films. This is partly due to the (much) lower production volumes (and therefore less opportunity for economies of scale) and the shorter period of time over which bio-based plastics have been commercialised compared with the long history of development experienced by fossil-based plastics. Yet, it is currently unclear the extent to which bio-based plastic production processes can be (further) improved in the future to be competitive with fossil-based plastics.

For other impact categories than Climate Change the results also showed a similar picture. R-LDPE film had the lowest impact in nearly all of the remaining 15 impact categories[236] compared to the other alternatives, while virgin LDPE film had a better performance than biodegradable films in not less than half of the remaining categories.

Despite the outlined limitations and the illustrative nature of the study, it may be argued that using LDPE mulch film, when it is recycled at high rates and then used in a closed loop to produce new mulch film, is a scenario that is likely to show the lowest environmental impact for categories that can be currently quantified in LCA (e.g. excluding potential impacts from plastic release in the open environment). Even if the bio-based feedstocks used to produce biodegradable mulch film improve their production efficiencies in the future, the fact that the material cannot be recovered for further use means that it will always be made from virgin materials. From a circular economy perspective this is not optimal, but it also remains to be seen whether it is truly possible to effectively collect and recycle conventional fossil-based mulch films to avoid the trade-offs associated with the build-up of plastics in the environment. Moreover, it still has to be proven whether real closed loop recycling of non-biodegradable mulching film does not incur additional environmental impacts due to e.g. removal of soil contamination[237], thus reducing the advantage compared to other available alternatives.

With regard to other end of life treatments, conventional mulch films are often incinerated or landfill due to the lack of recycling. The study also modelled these alternatives for LDPE mulch films and found that both these fates are worse than recycling for the majority of impact categories including climate change. The 100% Incineration scenario was the worst fate from a climate change perspective and therefore makes LDPE the worst material option overall under these circumstances. This is also likely to worsen as the electricity generated from incineration offsets more low carbon sources in the future.

One aspect that was not modelled by the JRC study is any effects of film contamination in other residual treatments due to the lack of representative data. This may be important particularly for landfill when organic matter (e.g. crop residues) that may be attached to the plastic breaks down to form methane. Without further research into this aspect, it is not possible to determine and compare the impact but does provide more reason to prevent highly contamination mulch films from entering landfill.

4.3.4 Conclusions on Environmental Risk

Assessing the possible environmental impacts of using BDMs is critical to evaluating their potential as a substitute for conventional plastics in agriculture. The review of evidence in this section has shown that;

- *during use*, the effects of BDMs on soil health are comparable to the effects of conventional mulches although there is a learning process for the grower when

[236] I.e. all categories except for Ozone Depletion.

[237] Notice that the JRC study assume manufacturing of recycled LDPE film out of low-contaminated LDPE waste, and not from heavily contaminated used mulch film.

transferring from conventional to BDMs to achieve optimum performance. This is not seen as a barrier if appropriate training and support is provided by the film supplier (which is typically the case);

- material, climate and soil factors interact to affect the biodegradation rate, such that the same product may degrade fully within two years in one location but may take a longer or shorter time in another;
- as full biodegradation of BDMs once tilled into the soil can take more than one year, accumulation in the soil is likely to occur in places where the average soil temperature is <15^{o}C but this stabilises at a low level;
- Once application of BDMs ceases or if a fallow year is included, the presence of BDMs in the soil is likely to rapidly decrease (1-2 years) to zero in temperate climates (soil temperature >10^{o}C); this is in contrast with conventional plastic which will remain at the same concentration.
- the environmental effects of the long-term low concentrations of BDM in the soil are not known. There is a lack of long-term studies looking into accumulation of BDMs;
- The extent to which either conventional mulch films or BDM films may leach into waterways or other habitats has not been the subject of any specific study. If leaching or wind transportation does take place for conventional film fragments there is existing evidence to suggest there would be several (but as yet unquantifiable) negative ecosystem impacts. For BDMs, the impacts are likely to be comparatively less, but as aquatic biodegradation testing is not typically conducted on these materials, there is no guarantee that the impact would be zero;
- When using life cycle assessment (LCA) as a tool to compare environmental impact, current evidence suggests that conventional mulch films have a lower environmental impact compared with BDMs under most impact categories. Incorporating recycled material in conventional films increases the number of impact categories where BDMs are outperformed. However, the occurrence and negative impacts associated with residual conventional mulch film remaining on the field are not yet possible to be comparatively quantified; and,
- Biodegradable mulch films are likely to reduce the occurrence and persistence of plastics in the open environment, but this is a trade-off that is not possible to capture through typical LCA methodologies at present, and biodegradation pathways of biodegradable plastics in soil still have to be completely understood.

Table 4-3 summarises the key trade-offs between conventional and BD mulch films. It highlights the considerable unknowns that prevent definitive conclusions at this time. Whilst conventional mulch films once recycled are thought to have lower overall life cycle environmental impact than BDMs, recycling does not typically take place at this time. Whilst it is possible to incentivise recycling of collected material to take place, further research is required to determine whether it is possible to consistently remove all traces of conventional film from the field after use. If this is not possible then a key trade-off of plastic pollution in the environment vs greenhouse gas emissions (as well as most other environmental impact categories) exists. Changes in technology that improve removal and provide cleaner material into the recycling system as well as advances in the production of bio-based feedstocks may also affect whether each practice is more preferable than the other in future.

Table 4-3: Summary of Mulch Film Material Environmental Trade-offs

Green = most favourable environmental scenarios; **Yellow** = mixed or uncertain scenarios; **Red** = least favourable environmental scenarios

<table>
<tr><th>Trade-off >>
Mulch Material[5]</th><th>Raw Materials and Production</th><th>Landfill</th><th>Incineration</th><th>Left in Soil</th><th>Recycling</th></tr>
<tr><td>Bio-based biodegradable</td><td rowspan="2">Generally higher impact than conventional[1]</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td><td>Releases biogenic CO_2; ~1/3 is converted to biomass[1]</td><td rowspan="2">Does not take place - material value is lost</td></tr>
<tr><td>Fossil-based biodegradable</td><td>Releases fossil CO_2; ~1/3 is converted to biomass[1]</td></tr>
<tr><td>Bio-based Conventional</td><td rowspan="2">Generally lower impact than biodegradable</td><td rowspan="2">Inert, but possibility of methane from organic residues</td><td>Releases biogenic CO_2</td><td rowspan="2">Persists[4]</td><td rowspan="2">Material is recyclable[3]</td></tr>
<tr><td>Fossil-based Conventional</td><td>Releases fossil CO_2</td></tr>
</table>

1. It should be noted that this may change as supply chains and manufacturing processes develop over time.
2. It is unclear exactly which proportions are converted to CO_2 or biomass. An indicative figure of 1/3 conversion to biomass similar to that of compostable plastics is provided.
3. Recycling of mulch films in the EU is not typically undertaken – future improvements to collection rates and policy options that encourage recycling are required.
4. It is unclear how much residual plastic typically remains in the field (due to improper removal or thinner films tearing) at this time
5. Materials can also be a combination of fossil and bio-based. This means both fossil and biogenic CO_2 can be released from the same product depending upon circumstances.

4.4 Economic Comparison

One of the reported barriers to wider acceptance of BDMs is that the material is usually considerably more expensive. A Spanish study compared prices for pepper farming and found 15µm biodegradable mulch films can range from €500 to over €1,000 per hectare compared with PE films which cost around €400 for the same thickness.[238] The same study compared the overall costs of using each material which are summarised in Figure 4-8. Other costs, not included in the figure remain identical, with the key differences being the removal and waste management of the PE mulch film. The film removal was undertaken mechanically, but no indication was given of the proportion that was recovered from the field. Despite this, the difference in material cost is still the overriding factor. Waste management—either landfill (€10) or recycling (€16)—was a relatively small cost and account for only 0.1% of the final net profit margin.

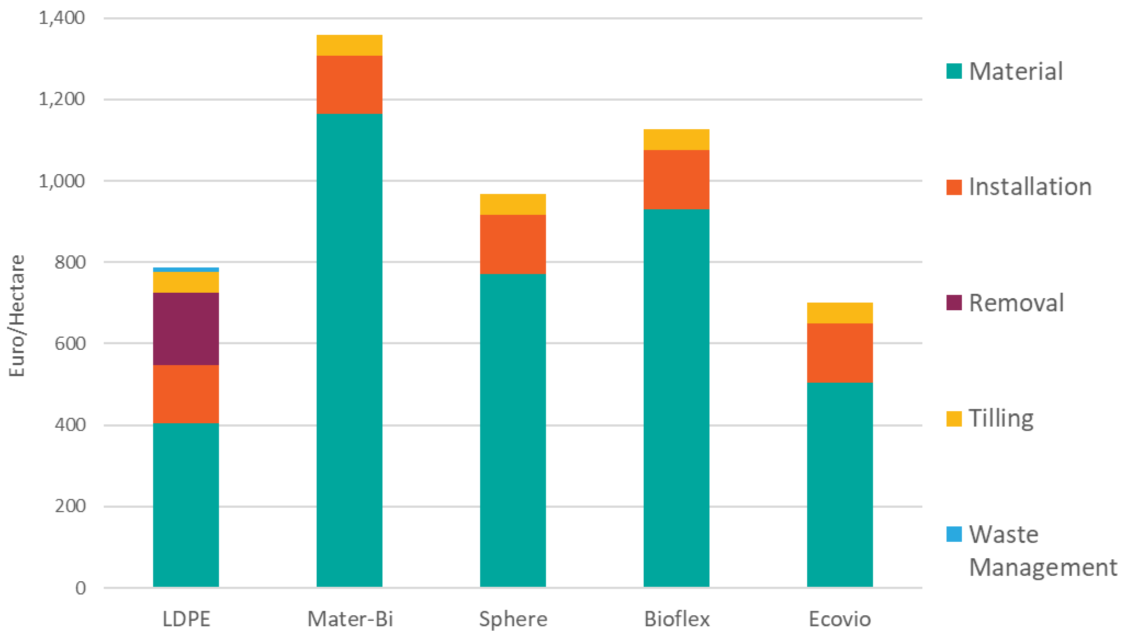
In Spain, some regional authorities have introduced economic (e.g. a 35% subsidy in Aragon) incentives to promote the use of biodegradable mulch films as a way of reducing plastic pollution; this brings the costs close to that of PE. As the study points out, this is likely not be enough of an incentive to change to a new system—at least for this crop type in Spain.

The issue here is that other costs of extended use of conventional plastic mulch have not been internalised. As discussed in Section 4.3.2, yield impacts could result from increased plastic contamination of soil in as little as 10 years. In the case of the Spanish pepper farming, a drop in yield of as little as 3% would offset the cost difference. However, much of this is theoretical and individual circumstances, crop type and climate will all influence whether there are financial benefits from switching to BDMs.

The final cost consideration is the thickness of the material – both PE and BDM in the study were 15µm thick. This is typical of BDMs, but is considerably lower than the recommended thickness required to aid effective removal of conventional plastic mulch films from the field (20-25 µm). Accordingly, for example, a 33-67% price increase for thicker material would increase the LDPE costs in Figure 4-8 to around €933-1067/hectare. This should form part of the consideration if thicker films become mandatory.

[238] Marí, A.I., Pardo, G., Cirujeda, A., and Martínez, Y. (2019) Economic Evaluation of Biodegradable Plastic Films and Paper Mulches Used in Open-Air Grown Pepper (Capsicum annum L.) Crop, Agronomy, Vol.9, No.1, p.36.

Figure 4-8: Mulch Film Cost Comparison



Source: Adapted from Marí et al.

4.5 Verifying Safety and Performance through Standards

There is currently no EU wide standard that specifies the test requirements for all plastics and products that claim to be biodegradable in soil. Mulching films, as a particular subset of plastics, have been the focus for standard setters with the introduction of an EU wide standard for biodegradable mulching films for use in agriculture and horticulture in 2018 (EN 17033:2018). Prior to this, France (NF U52-001 2005) and Italy (UNI 11495 2013) had developed their own country specific standards for mulching films. A detailed comparison of the standards is given in Appendix A.4.2.

The three standards (EU, French and Italian) specify laboratory testing of;

1) the chemical composition of the material;
2) biodegradation in soil; and,
3) eco-toxicity effects.

EN 17033 details the mechanical requirements for biodegradable mulch films of three different thickness classes <10µm, >10 µm, <15 µm and >15 µm. The requirements' thresholds are different to conventional plastics but are set to ensure that the film will perform satisfactorily,[239] however as this report has shown in Section 4.2.1 a degree of learning is needed to get the best performance from BDMs. The EU standard includes in its own Annex H an outline of best practice for the use of BDMs, although it is unclear to what extent these best practices are being adhered to, given that they are voluntary and that the grower would be unlikely to look at the standard directly.

Annex G of EN 17033 lays out an optional test process to ascertain if damage to the film during use can be attributed to the properties of the film or are attributable to biotic or abiotic factors. As the functionality of the film is dependent on the surface area covered during key growth stages of a crop any reduction in this coverage will affect performance and growers need to understand if this is occurring due to a limitation of the material or other reasons. If more than 10% of the surface area of the film is altered during use then the standard recommends that the material is tested as specified. It is unclear who would actually make use of this test and what the implications of this would be. It is more likely that a grower experiencing issues with a film would switch to another product.

4.5.1 Biodegradation Tests Within Standards

The three standards largely follow the soil biodegradation test laid out in EN ISO 17556 which calculates intrinsic biodegradation from laboratory measurements of evolved carbon dioxide. A sieved natural soil is used as the medium and temperature is to be kept constant within ±2°C in the range between 20-28°C, preferably 25°C. The validity

[239] The mulch film standard for conventional films (EN 13655) only details the mechanical requirements for films greater than 20 µm

criteria laid out in the standard EN17033 states that the material has passed if 90% biodegradation is recorded in comparison to a cellulose reference or in absolute terms within 24 months.

It is recognised that laboratory tests need to be carefully prescribed in order to be replicable, and therefore it is inevitable that they will only serve as a proxy for infield biodegradation where a complex interplay of biotic and abiotic factors is present.[240] Some authors have questioned whether ISO 17556 is an accurate indicator of how a product made from these materials will biodegrade when in real soil and suggest that the tests should be 'calibrated' by comparing results to actual field conditions.[241] This is problematic given the findings of Section 4.3.1 that the biodegradation rate for one material varies according to climate and soil conditions.

In EN 17033 the biodegradation requirement can either be met by the BDM or its components, i.e. tests can be performed either on the mulch film itself or on its plastic base material in pellet or powder form, without additives or the master batches. This has led to some discussion on the suitability of testing in powder form, though the particle size of powder samples have a thickness of a ~200 microns which is substantially higher than the film samples with a thickness of approximately 15µm.[242] This would therefore seem to be a satisfactory testing procedure as it would generate a slower biodegradation rate than expected in the field, assuming moisture content and temperature are the same in both conditions. However, given that testing in powder or pellet form is acceptable, this essentially means that it is the *material* that can be certified to the standard and not the *product* – i.e. a certified material can be made into a product of any thickness which would mean a variety of biodegradation times are possible in real-life conditions.

The duration of the test is set at a maximum of two years. Although tests have shown that in-field biodegradation for some BDMs can take several years,[243] [244] this does not undermine the choice of test duration which is intended to establish the material's potential for *inherent biodegradation*. Any material that passes the biodegradation test threshold of 90% degradation in two years should be able to completely degrade in the soil given sufficient time. This means that even in locations where biodegradation is

[240] Lambert, S., and Wagner, M. (2017) Environmental performance of bio-based and biodegradable plastics: the road ahead, *Chemical Society Reviews*, Vol.46, No.22, pp.6855–6871

[241] Hayes, D., and flury, markus (2018) *Summary and Assessment of EN 17033:2018, a New Standard for Biodegradable Plastic Mulch Films*, accessed 12 March 2020, https://ag.tennessee.edu/biodegradablemulch/Documents/EU%20regs%20factsheet.pdf

[242] OWS (2016) Expert Statement: (Bio)degradable Mulching Films

[243] Moreno, M.M., González-Mora, S., Villena, J., Campos, J.A., and Moreno, C. (2017) Deterioration pattern of six biodegradable, potentially low-environmental impact mulches in field conditions, *Journal of Environmental Management*, Vol.200, pp.490–501

[244] Wang, Z., Wu, Q., Fan, B., et al. (2019) Testing biodegradable films as alternatives to plastic films in enhancing cotton (Gossypium hirsutum L.) yield under mulched drip irrigation, *Soil and Tillage Research*, Vol.192, pp.196–205

slowed due to climatic factors, the material will degrade eventually leaving no residue. The model of accumulation in Section 4.3.2 shows that the concentration of BDM in the soil is likely to stabilize as they are continually degrading.

For those applications where tilling is not immediately possible, the Standard itself is somewhat unclear; on one hand it provides a classification system based on film life which includes vineyards and orchards in the >12 month class (Annex G); however, it also stipulates in Annex H that;

> *"Growers will make sure that biodegradable mulch films are incorporated in soil and maintained buried to allow the biodegradation of film materials to progress."*

It is clear the testing regime (ISO 17556) is only applicable to films that have been buried *in soil* and yet there appears to be instances where this will not ever take place or will not for a number of years. There appears to be a lack of consensus around whether this is a problem in practice. Interviews with two experts that have been involved in pre-normative testing for EN 17033.[245]One view is that soil organisms will still be present and will biodegrade material that remains on top of the soil, but this will happen at a much slower rate.[246] The other view is that, whilst this might be the case, this is unknowable and untestable currently and that the EN 17033 does not provide a methodology that can possibly verify this particular scenario.[247] Currently, EN 17033 does not make it clear, or provide a specific requirement that it does not cover mulch film applications that are not tilled into the soil. As the soil test (SO 17556) is designed to replicate ideal conditions for biodegradation ***in** soil* the implication of this is that the material will take longer to biodegrade on the surface of the soil where there is less contact with microbes and reduced moisture. This increase in time and exposure may also increase the risk of the material being transported into other environments.

In conclusion, the biodegradation tests within EN 17033 are sufficient to ensure that there is a low risk of accumulation of film material within the soil. However, it does not (nor does it seek to), guarantee that the material will be completely biodegraded within two years, as the climatic and soil conditions can act to slow field biodegradation compared to the laboratory conditions. Extended biodegradation times may lead to a risk of the material escaping into other environments, but the extent to which this may happen is unknown. This uncertainty is a gap in the current knowledge base, but is not likely to be a significant barrier to the use of biodegradable mulch films. **The lack of certainty around the use in less than ideal conditions is balanced by the certainty that the alternative conventional films *will* persist and cause harm if not fully removed from the field.**

---

[245] Bruno De Wilde, OWS and Prof Demetres Briassoulis of Agricultural University of Athens
[246] Expert opinion of Bruno de Wilde, OWS
[247] Expert opinion of Prof Demetres Briassoulis, Agricultural University of Athens

As an ongoing low, but stabilised and non-accumulating, concentration of BDM material in the soil is therefore likely to be inevitable, the effects of this are assessed through the eco-toxicity tests within the standards which are discussed in the following section.

4.5.2 Ecotoxicity Tests within Standards

The first way that standards aim to ensure that materials will not result in environmental harm is by restricting substances within the materials. Appendix A.4.2. compares the requirements of the three standards. All three limit heavy metals, in addition, EN 17033 limits Substances of Very High Concern (SVHC) to 0.1% concentration.

Possible adverse effects are explored with tests using soil in which a BDM has degraded for 6 months at an initial concentration of 1%. For a typical mulch film of 15µm the concentration in the soil when tilled in is 0.0063%[248], even with annual applications the maximum accumulation level will be 0.012%. This is one hundredth of the test level, which indicates that the tests for eco-toxicity are testing at a concentration far in excess of what is likely to be observed in reality.

The eco-toxicity tests in the three standards are similar in scope but specify different tests. All three test on plants (germination and growth) and earthworms. EN 17033 includes an additional test on microorganisms through the mechanism of nitrification inhibition. The tests in EN17033 cover all organism groups and explore the different soil exposure pathways that are present, as plants and microorganisms experience toxicants mainly through contact and uptake of soil water while earthworms will ingest soil material.[249]

It has been suggested that the ecotoxicity testing could be strengthened by expanding the range of organisms that are included, and by using tests that explore long term impacts.[250] The chronic test on earthworms includes an exposure period of 56 days and records impacts on the number of offspring and mortality rate. This period is designed to be around twice the length of the reproductive cycle of earthworms, but as earthworms can live for several years there is still the possibility of cumulative chronic effects going unnoticed by this test.

One Novamont funded study tested a particular BDM on a wide range of organisms and found that where effects in the performance of organisms was seen this was similarly observed in the test using cellulose as a control. The authors conclude that the BDM tested can be described as '*innocuous for agricultural use*'.[251] Concerns have also been

---

[248] OWS (2016) Expert Statement: (Bio)degradable Mulching Films
[249] Hayes, D., and flury, markus (2018) *Summary and Assessment of EN 17033:2018, a New Standard for Biodegradable Plastic Mulch Films*, accessed 12 March 2020, https://ag.tennessee.edu/biodegradablemulch/Documents/EU%20regs%20factsheet.pdf
[250] Sforzini, S., Oliveri, L., Chinaglia, S., and Viarengo, A. (2016) Application of Biotests for the Determination of Soil Ecotoxicity after Exposure to Biodegradable Plastics, *Frontiers in Environmental Science*, Vol.4
[251] ibid

raised over the possible effects of compounds that are released during biodegradation as the ecotoxicity tests use soil in which biodegradation of the BDM has been underway for six months. It is argued that the effects of this are not yet understood as current tests do not take into account the changing needs of organisms at different phases.[252] On the other hand, BDM producers claim that "*the monomers and plasticisers that can be released during biodegradation are themselves totally biodegradable in soil and safe if assessed by carrying out an evaluation scheme based on the REACH methodology*."[253] While it cannot be ruled out that there are possible ways in which BDM biodegradation may have a negative impact on soil ecosystems that is not currently being captured, the current ecotoxicity tests and constituent restrictions are sufficient to ensure this risk is relatively low especially in comparison to the issues identified with the accumulation of conventional plastics.

In conclusion, the evidence reviewed has shown that current ecotoxicity testing in EN 17033 is:

- at a concentration sufficient to cover regular use of the BDMs; and,
- covers the three organism groups and exposure pathways, but could be strengthened by increasing the range of organisms tested on.

However:

- the tests do not explore possible long-term impacts of low concentrations of material in the soil; and,
- by performing the tests using soil in which the material has already biodegraded for six months, the tests do not assess any initial impacts during the main biodegradation phase such as the release of compounds or the physical impact of the BDM fragments on investigates before they are biodegraded.

Further study is needed to explore the potential of these last two points but at present it is likely that the risks they present are low. Therefore, it can be concluded that if products are required to meet the EN 17033 standard the risks are managed and kept low enough to support the more widespread adoption of BDAPs. However, given the high level of material innovation in this sector, it would be prudent to review the standard regularly in order to maintain its stringency.

---

[252] Bandopadhyay, S., Martin-Closas, L., Pelacho, A.M., and DeBruyn, J.M. (2018) Biodegradable Plastic Mulch Films: Impacts on Soil Microbial Communities and Ecosystem Functions, *Frontiers in Microbiology*, Vol.9

[253] Novamont (2020) Position_Paper_Mulch film_Novamont_Apr20.pdf

4.6 Application Risk Summary

From the preceding discussion, it is clear that the use of biodegradable plastics in agriculture has some significant advantages in some scenarios. However, there are likely to be other scenarios and products where advantages are lessened and the risk of negative consequences is increased. Table 4-4 provides examples of these products/scenarios in order of environmental risks. As there is no way to quantify the risk, this is shown in terms of relative risk.

Low risk applications are those where the material is designed to be tilled into the soil, and these have been studied extensively both in industry tests and published studies, to understand how long biodegradation will take. These have a standard associated with them and include mulch films for short and long cycle crops in warm and temperate climates.

Medium risk applications include mulch films in colder climates or where there is the possibility of tilling not taking place. There is a greater uncertainty around what might happen to the plastic as it takes longer to biodegrade and may be transported into other environments. The uncertainty and therefore the risk could be reduced with additional research and/or more clarity for farmers in these more difficult to manage situations. **Also, in the medium risk are examples of other products that may benefit from being biodegradable in certain circumstances** such as drip tape and tree protection. The former would be used alongside the BDM to eliminate the additional step of removing irrigation pipes from the field. However, there are significant technical barriers to this product presently (i.e. creating a material that will carry water, but not prematurely biodegrade), that mean it is not commercially available.[254] Tree protectors are often in place for many years and can be forgotten, but the biodegradation time is unknown and there are no test standards that are applicable at present. However, on balance, it is likely that a slow degrading biodegradable material would have a lower impact on the environment than a conventional version that is discarded. Despite this, the optimal environmental solution would always be to remove it to prevent the risk, but the practicalities can make this problematic.

High risk applications encompass the other main agri-plastic products (e.g. silage and greenhouse films) that have no research associated with biodegradation times and would simply be left in situ. Leaving high volumes of films in situ with no controls constitutes a higher risk due to the uncertainty around what will happen to the material over time and the increased likelihood of it being dispersed throughout the environment as it fragments initially. All of these products can and are also capable of being collected, but with wide variance levels of this currently.

[254] Hiskakis, M., Babou, E., and Briassoulis, D. (2011) Experimental Processing of Biodegradable Drip Irrigation Systems—Possibilities and Limitations, *Journal of Polymers and the Environment*, Vol.19, No.4, pp.887–907

Table 4-4: Biodegradable Agricultural Plastic Application Risk Summary

Env Risk	Product/ Application	Scenario	Disposal	Climate	Time to Biodegrade	Biodegra-dation Standard Available
Low	Mulch film	Short cycle crop[1]	Tilled into soil	Warm (e.g. Italy)	<2 years[3]	EN 17033
Low	Mulch film	Short cycle crop[1]	Tilled into soil	Temperate (e.g. France)	~3 years[4]	EN 17033
Low	Mulch film	Long cycle crop[2]	Tilled into soil	Warm (e.g. Italy)	~3 years[3]	EN 17033
Low	Mulch film	Long cycle crop[2]	Tilled into soil	Temperate (e.g. France)	~4 years[4]	EN 17033
Medium	Mulch film	Short cycle crop[1]	Tilled into soil	Cold (e.g. Sweden)	Unknown	EN 17033
Medium	Mulch film	Long cycle crop[2]	Tilled into soil	Cold (e.g. Sweden)	Unknown	EN 17033
Medium	Mulch film	Perennial crop	Left on soil surface	Warm (e.g. Italy)	Unknown	×
Medium	Mulch film	Perennial crop	Left on soil surface	Temperate (e.g. France)	Unknown	×
Medium	Mulch film	Perennial crop	Left on soil surface	Cold (e.g. Sweden)	Unknown	×
Medium	Drip Tape	Used alongside BDM	Tilled into soil	Any	Unknown	×
Medium	Tree Protection	Protect trees for 5+ years	Left in situ	Any	Unknown	×
High	Twines and nets		Left in situ	Any	Unknown	×
High	Silage Stretch Wrap		Left in situ	Any	Unknown	×
High	Silage films		Left in situ	Any	Unknown	×
High	Low tunnel films		Left in situ	Any	Unknown	×
High	Greenhouse films		Left in situ	Any	Unknown	×

Notes

1. For an 15µm film, <six months
2. Assumes a thicker (~20-25 µm) film will be required, six to twelve months
3. Based on 15°C average soil temperature. Modelled results using data from Ghimire (experiments conducted at 12°C) extrapolated using the temperature regression model from *Pischedda et al*.
4. Based on 10°C average soil temperature.
5. Based on 5°C average soil temperature. This is likely to be lessened by choosing a more readily biodegradable material e.g. starch based. However, any ground freezing during winter will prevent biodegradation from proceeding until warmer temperatures arrive.

4.7 Proposing and Testing Criteria for the Use of Biodegradable Agri-Plastics

From the point of view of waste disposal, in the case of biodegradable plastic, there is no evidence to suggest that the material itself provides any measurable agronomic benefits when incorporated into the soil after its useful life is over (this is distinct from the agronomic benefit from the mulch film itself which is comparable between biodegradable and conventional plastics). Some carbon from the biodegradable plastics appears to be incorporated into the biomass but at least half is 'lost' to CO_2 air emissions.[255] Biodegradable plastics that are not incorporated into soil, but left in situ are unlikely to provide any benefit. **This leads to the premise that recycling would be above soil biodegradation in the waste hierarchy and means that the default position should be to focus on the collection and recycling of agri-plastics. However, this should also be weighted up against the evidence for the disbenefits associated with conventional plastic being incorporated into soil if it is considered not possible to fully remove the material. Currently, it is not clear whether 100% removal from land is feasible.**

It is also important when determining the beneficial use of BDMs, to set a clear standard for conventional mulch films. It is evident that the design of conventional mulch films is often sub-optimal to achieve high field recovery rates and subsequent recycling. Whilst EN 13655 specifies a minimum thickness of 20 µm, this standard is not mandatory which leads to thinner materials being used, which in turn, increases the likelihood of plastic residues remaining. There appears to be a strong argument to set a minimum mandatory thickness and/or tensile strength requirement (possibly linked to the standard) that would not only reduce plastic pollution, but increase recycling as contamination is also reduced. The exact minimum thickness that should be specified is not clear at present. This requires further study to determine how thick the material needs to be for 100% removal from the field to be achieved. Results from the JRC's LCA on the subject (see Section 3.4.4) found that, from a material production perspective, conventional plastic is preferred even at 35 µm. Improved recycling and an incorporation of recycled content may allow an even thicker material to still be the preferred option.

The reality is that it is desirable to avoid any plastic in soils that is likely to accumulate. The modelling suggests that even at =/>95% recovery of conventional mulch from the field, that accumulation will reach problematic levels within 50-100 years. This means that it may not be an immediate problem, but one that is cumulative and cannot be reversed. Each percentage point improvement in recovery will have a massive effect and the focus on good design and removal practices should be prioritised. Whilst this suggests a wholesale move to BDMs (from the perspective of plastic pollution) caution

[255] Hann, S., Molteno, S., Hilton, M., and Favoino, E. (2020) *Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy*, Report for European Commission DG Environment, February 2020

should be taken when suboptimal conditions are present (as identified in Section 4.6). There are also design limitations currently with BDMs such as the inability to be produced in a transparent version which limits the number of possible applications.

Presently, the main use of BDAPs is in mulch films, and this is where the academic research has largely focused hence the similar focus in this report. **It is clear that BDMs offer the grower an additional choice with benefits that are compelling and there appears to be no reason to legislate to prevent these from being used.** However, new materials are being developed and new applications are being suggested for BDAPs such that there is a need for a set of principles that can guide the use of these products toward applications where a genuine benefit can be achieved and prevent misuse and false claims. This not only protects the existing market of BDAPs from products with similar, but unproven claims, but provides a framework for growth. Table 4-5 summarises the key principles identified in the preceding discussion to propose criteria that should ideally be fulfilled that will reduce environmental risks (recognising that this is focused on comparative risk) whilst maintaining the waste hierarchy and focus on circular economy principles.

Table 4-5: Criteria for Biodegradable Plastic Applications in Agriculture

Criteria	Justification
Primary Tier	
The use of conventional plastic results in negative environmental impacts associated with soil accumulation/ leakage into environment	The product/application is known to be a source of plastic pollution emitted into the environment during use/disposal. Plastic (or non-plastic) applications that are not associated with negative impacts should aim for recyclability to retain material value.
The product cannot feasibly be removed, collected and disposed of responsibly, leaving no residues at the end of life	The focus should be on collection and recycling. Products that can feasibly be removed after use and collected (even if policy mechanisms/incentives are required) should not be biodegradable.
Secondary Tier	
Similar or improved product specification and performance compared with the conventional alternative during use can be achieved	The alternative product should provide close to the same functional performance otherwise it is unlikely to be adopted.
In-situ testing has been conducted to observe the biodegradation time expected in a particular climate	To reduce the risk of unintended consequences, real-life testing should be undertaken which can form the basis of pre-normative research.
A standard test method and biodegradation threshold is available (e.g. EN 17566 and EN 17033)	The existence of a standard that allows testing and verification means that producers have a standard to aim for and consumers can specify this and be sure of performance.

There are two tiers of criteria; primary and secondary. The primary tier consists of criteria that represent constants that are unlikely to change over time and should be fulfilled before the secondary criteria are addressed. Secondary criteria are evidence-based criteria that can be investigated for products/applications that meet the primary criteria. This aims to conserve resources that might be spent on product development, biodegradation testing and standard development for unsuitable applications.

Table 4-6 takes these criteria and applies them to the common agricultural plastic applications identified in this report as well as some niche and/or novel example applications.

Table 4-6: Applying Criteria for BD Plastic Applications in Agriculture

✓= fulfils criterion, ✗ = fails criterion, ✓✗ = evidence base is unclear/or being developed

Criteria	Mulch Films - short cycle crop	Mulch film for rice production	Irrigation Drip Tape	Tree Protection	Twines and Nets	Silage Wraps	Greenhouse Films
Primary Criteria							
The use of conventional plastic results in negative environmental impacts associated with soil accumulation/ leakage into environment	✓	n/a	✓✗	✓	✓	✓	✓
The product cannot feasibly be removed, collected and disposed of responsibly, leaving no residues at the end of life	✓	✓	✓✗	✓✗	✓✗	✗	✗
Secondary Criteria							
Similar or improved product specification and performance during use can be achieved	✓	n/a	✗	✓	✓✗	✗	✗
In-situ testing has been conducted to observe the biodegradation time expected in a particular climate	✓	✓✗	✗	✗	✗	✗	✗
A standard test method and biodegradation threshold is available	✓	✓✗	✗	✗	✗	✗	✗

The results of Table 4-6 show that only mulch films are considered to be a suitable application for biodegradable materials at this time which is consistent with the findings of the research for this report. The evidence base is strong for this application and it is the only one that can be verified through the use of a standard. At the other end of the scale, both silage wraps and greenhouse films fail on the primary criterion that collection cannot be achieved. Whilst products such as greenhouse films are not being promoted by biodegradable plastics producers this provides a framework that justifies continuing that position.

It is clear that the property of biodegradation should not be used in agri-plastics as a means of removing the responsibility for plastic waste collection in agriculture, which means that the environmental impact associated with mismanagement should be addressed through other measures. For both silage wraps and greenhouse films there is also a significant challenge in achieving a performance specification that matches conventional plastics; transparency is hard to achieve for greenhouse films and the need for a long lifetime makes biodegradable plastics prohibitive. Achieving an air tight, strong and long lasting covering for silage also runs counter to the properties of current biodegradable plastics. Similarly, for twines and nets these are also less suitable for biodegradable plastics as the application requires a a high tensile strength, which is harder to achieve with these materials (whilst also maintaining biodegradable properties).

Of more interest are the products that show promise for biodegradable plastic application, but lack the evidence to support these at present. A worked example of this is provided in Figure 4-9 for tree protection to demonstrate the thought process and highlight the key barriers that exist for this and similar products.

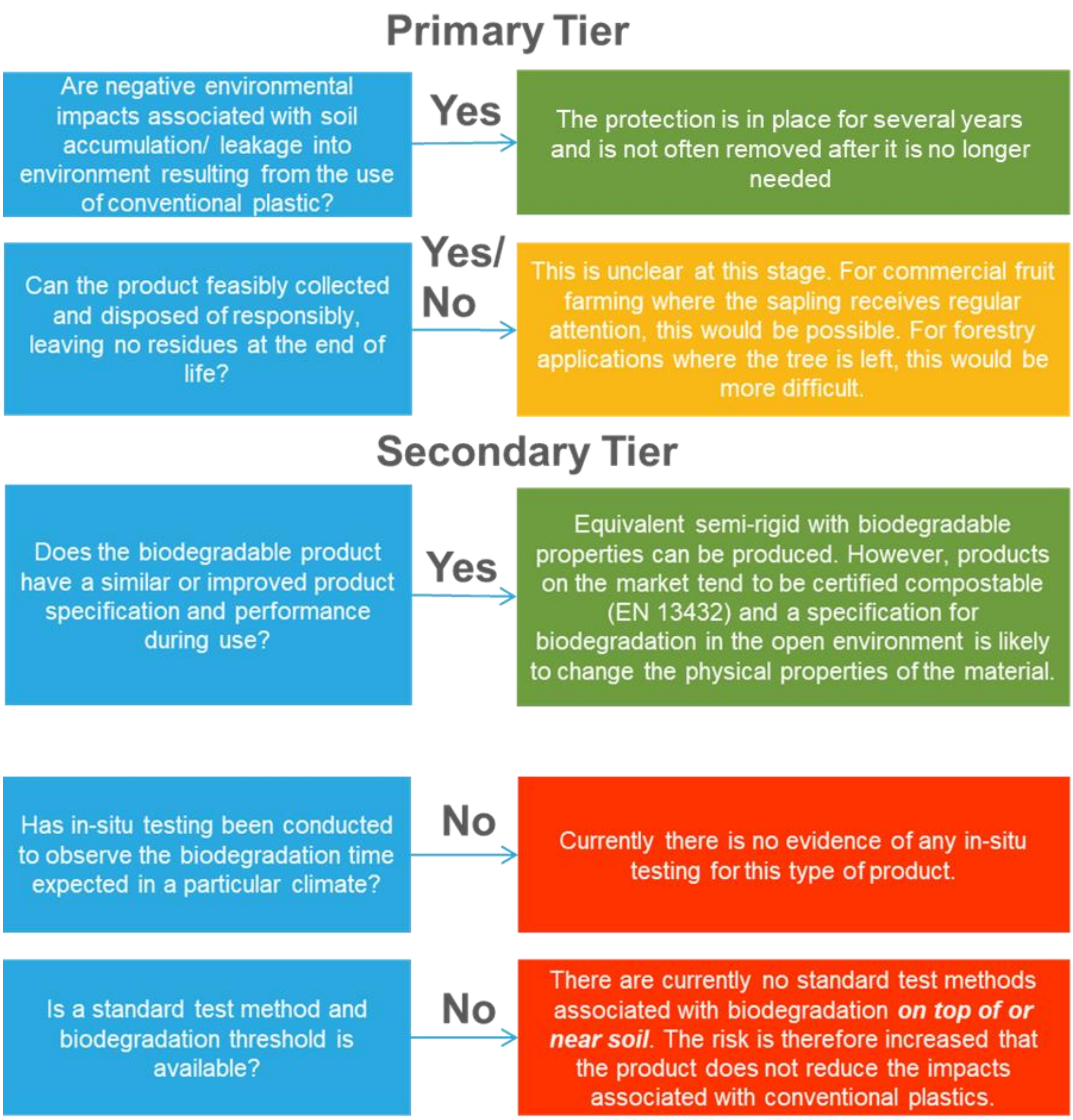
Whilst there is an ambiguity over the ability to collect tree protectors at the end of life, the main barrier is the lack of a standard test method than can verify biodegradation performance. Evidence suggests that those materials that are *inherently biodegradable at ambient temperatures* will likely have a lower impact if left in the open environment (where they might end up in water courses) regardless of whether they meet a specific threshold—unless 100% of the material ends up in an environment where little biodegradation may take place (the deep sea for example). As identified in Section 4.3.1.1, certain material such as starch, cellulose and PHAs have a higher inherent biodegradability and therefore are likely to pose less of a risk, however it is often difficult to achieve the required material properties on their own, which is why blends are used in BDMs to balance these aspects. Equally, a high biodegradability is only suitable if this is function is required immediately and not after an extended use period exposed to the elements.

For products that can often be left in the environment, such as tree-protection, there is an argument for the use of biodegradable materials to reduce the impact —even if full biodegradation is not always achieved because of the particular conditions, it may be a better alternative to conventional plastic remaining forever. However, the lack of standardisation and certification for products other than BDMs makes it impossible to differentiate between products made from materials with an evidence base for biodegradation and ones that do not perform as claimed. It is clear that standardisation is critical in creating a level playing field and preventing false claims.

It is for these reasons that no other biodegradable agri-plastics should be promoted at EU level at this time and new product applications should refer to the criteria for guidance around whether may be acceptable. Without a way of testing and verifying open environment biodegradation (and the difficulty of doing so), the focus should be on effective implementation of schemes (e.g. EPR) that make a compelling case for farms to collect and manage all plastic waste appropriately.

Figure 4-9: Applying the Criteria to Tree Protection

For use in farming or forestry – plastic spiral guards that wrap around young trees to protect from rabbits and other small animals.



5.0 Baseline of Agri-Plastics Consumption, Waste Generation and Management

A baseline of agricultural plastics consumption, waste generation and waste management routes in the EU28 was modelled and is presented in this section.

The baseline is based on historic data gathered and presented for Section 2.0. Stakeholder views on the future behaviour of the agricultural plastics market and waste management were also used to guide the modelling of forward projections.

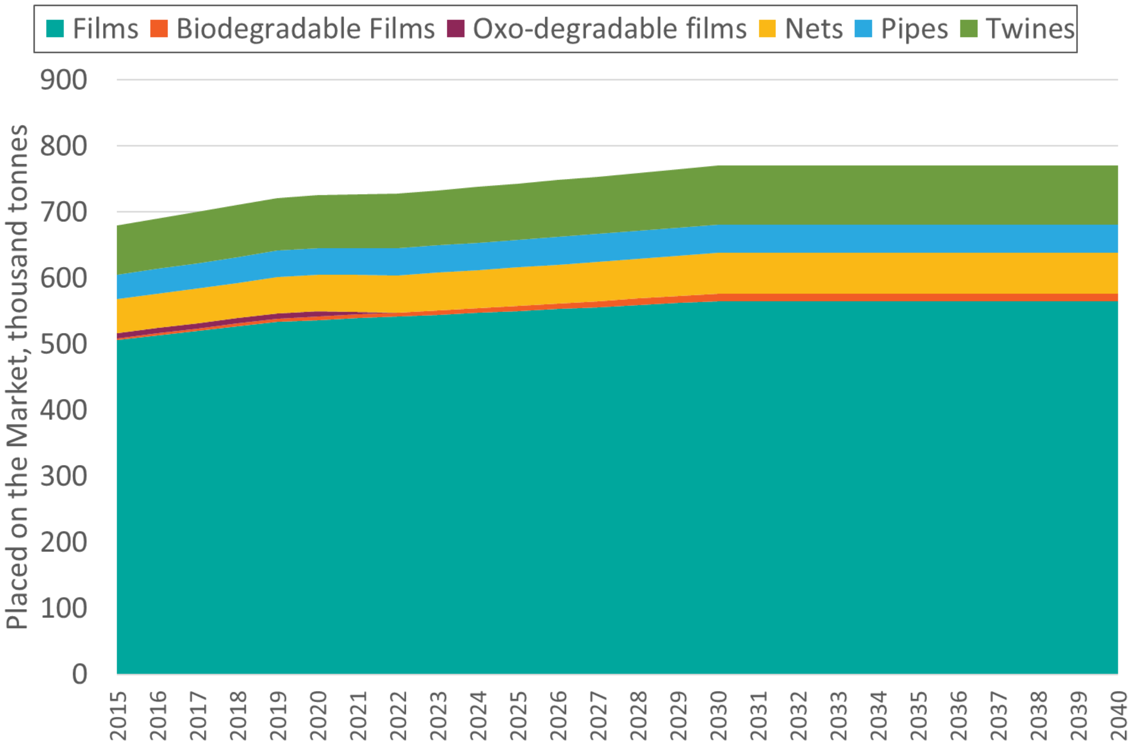
It is important to note that the majority of data used in this baseline are based on single data points, mainly from European trade associations. Statistical reporting of agricultural plastics data in Europe is still relatively undeveloped. This has necessitated the use of carefully considered estimates and assumptions for some data inputs and modelling parameters. These are noted throughout this report, and wherever possible have been evidenced in reference to known data points.

An overview of the methodology and assumptions used in the modelling is presented in Appendix A.6.0, and the baseline outputs discussed below.

5.1 Plastic Consumption and Waste Generation

Placed on market and waste generation data and projections are presented in this section. Firstly, baseline data and future projections in consumption for major agricultural plastic categories are provided in Figure 5-1. This figure demonstrates the modelled increase in total consumption from 721 thousand tonnes in 2019 to 771 thousand tonnes in 2030. As discussed in Section A.6.2.1, waste generation is modelled to increase in proportion to the tonnage placed on the market, from 1,188 thousand tonnes in 2019 to 1,262 thousand tonnes in 2030, with the quantity of plastics placed on the market assumed to stay constant from 2030 onwards.

Figure 5-1: Placed on Market / Consumption of Agricultural Plastics in the EU28, Thousand Tonnes (2019 to 2040)



A detailed breakdown of APE Europe data for placed on market and waste generation data in 2019 is provided in Table 5-1[256]. As shown in Figure 5-1, the agricultural plastics market is clearly dominated by films, with stretch film, silages and greenhouses having the highest placed on market tonnages. The quantity of waste generated is higher than plastics placed on the market. According to discussions with industry, this is mainly due to the additional soil content in generated waste.

Table 5-1: Placed on Market and Waste Generation in the EU28, Thousand Tonnes (2019)

	Placed on the Market	Waste Generation
Greenhouses	120	150
Mulch film	83	249
Small tunnels	56	112
Stretch film	146	219

[256] APE Europe (2020) *Plastics Data*

	Placed on the Market	Waste Generation
Silages	121	182
Non-woven nets	8	16
Protective nets	5	5
Bale net	50	75
Irrigation pipe	20	24
Drippers	20	24
Twine	80	120
Biodegradable mulch films	5	5*
Oxo-degradable agri-plastics	8	8*
Total	**721**	**1,188**

** We have followed a different reporting definition to APE Europe and included bio and oxo-degradable plastics in waste generated data. For these applications the generated 'waste' is not collected and is assumed to remain in the soil.*

5.2 Waste Collection

The collection rate describes the proportion of waste generated that is collected through national collection schemes, and therefore for which data is reported (and recorded by APE Europe). The remaining fraction of waste is denoted in our modelling as 'unaccounted for' waste, and includes both plastic and soil. As discussed in Section A.6.1, 'unaccounted for' waste includes the following collection/management routes:

1) Collected for landfill and recycling with local solutions (not related to national collection schemes);
2) Unwanted disposal methods (e.g. burnt on-site, burying); and
3) Left in the environment.

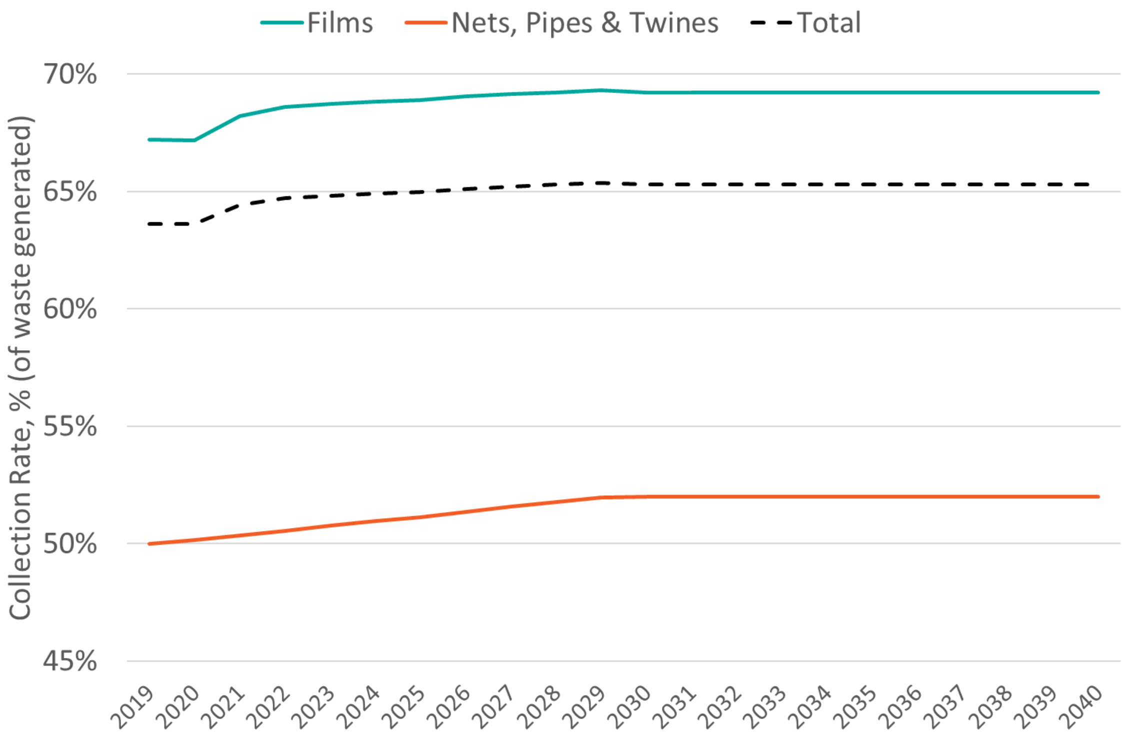
There is very little available data on the proportion of waste going to each of these destinations, although there is some literature which estimates the quantity of waste burnt openly (see Appendix A.6.1), which is disaggregated from other 'unaccounted for' destinations.

As discussed in Section A.6.2.2, future collection rates are projected based on an assumption that best-practice collection rates will be achieved within 7 years (mandatory EPR), and within 9 years (voluntary EPR) for Member States with existing or planned national collection schemes.

Member States are obligated, under Article 11 of the Waste Framework Directive (WFD), to separately collect plastic waste where technically, environmentally and economically practicable to do so. We have assumed that EPR schemes provide the primary route to achieving compliance with these requirements, however, it is not reasonable to assume that all Member States will implement EPR schemes in the future (i.e. in the baseline) purely due to the separate collection requirements of the WFD, particularly given that they are already required to comply with this legislation and have not as yet done so in many cases (only a minority of Member States currently have EPR schemes). Moreover, it is the purpose of this work to model additional policy options to achieve or move towards achieving this eventual goal (of compliance with the WFD), potentially via the mandated implementation of EPR schemes. This is discussed further in Section A.6.2.3.

Modelled collection rates are presented in Figure 5-2. Rates in 2019 are from APE Europe data. This data reports an average collection rate for films of 67%, and 50% for all other applications.

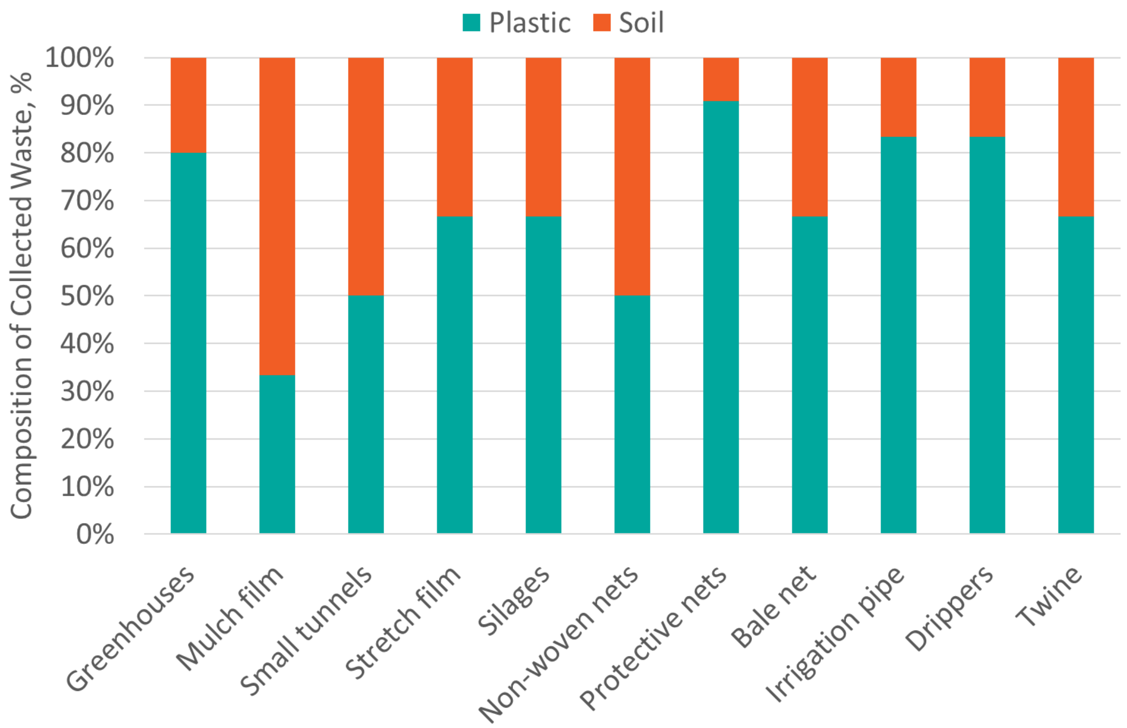
Figure 5-2: Baseline Collection Rates, % (2019 to 2040)



The baseline collection rates demonstrate relatively little change over the modelling timeframe. The average collection rate (based on APE Europe data) in 2019 was 63.6%. EPR schemes planned by the UK and Spain (Andalusia) to start in 2020 are assumed to have an impact on collection rates from 2021 onwards, leading to almost a 1% increase in the average EU collection rate (to 64.4%). From 2021 onwards, there is an increase in collection rate as performance of existing EPR schemes improves to meet best-practice collection rates. However, only a further ~1% increase is achieved, as average current collection rates (based on APE Europe data) are already close to best-practice rates. Furthermore, increases in collection rate only apply to applications within the scope of existing schemes, most of which are limited to a select number of applications (see Section 2.6).

Of this collected waste, Figure 5-3 shows the relative proportion of plastic and soil for each waste application, based on APE Europe data.

Figure 5-3: Composition of Collected Waste, % (2019)



5.3 Final Destinations

Collected waste is sent to sorting and reprocessing facilities where soil and other contaminants are removed and the remaining plastic recycled into secondary material. Recycling is the most environmental beneficial treatment option (with the exception of reuse where possible) for agricultural plastics waste.

Alternatively, in some collection systems, collected waste is sent directly to landfill and/or incineration facilities. This is due to a range of economic and/or technical reasons, such as poorly developed markets for end-material, lack of recycling infrastructure, or excess soil contamination leading to technical difficulties in the recycling process.

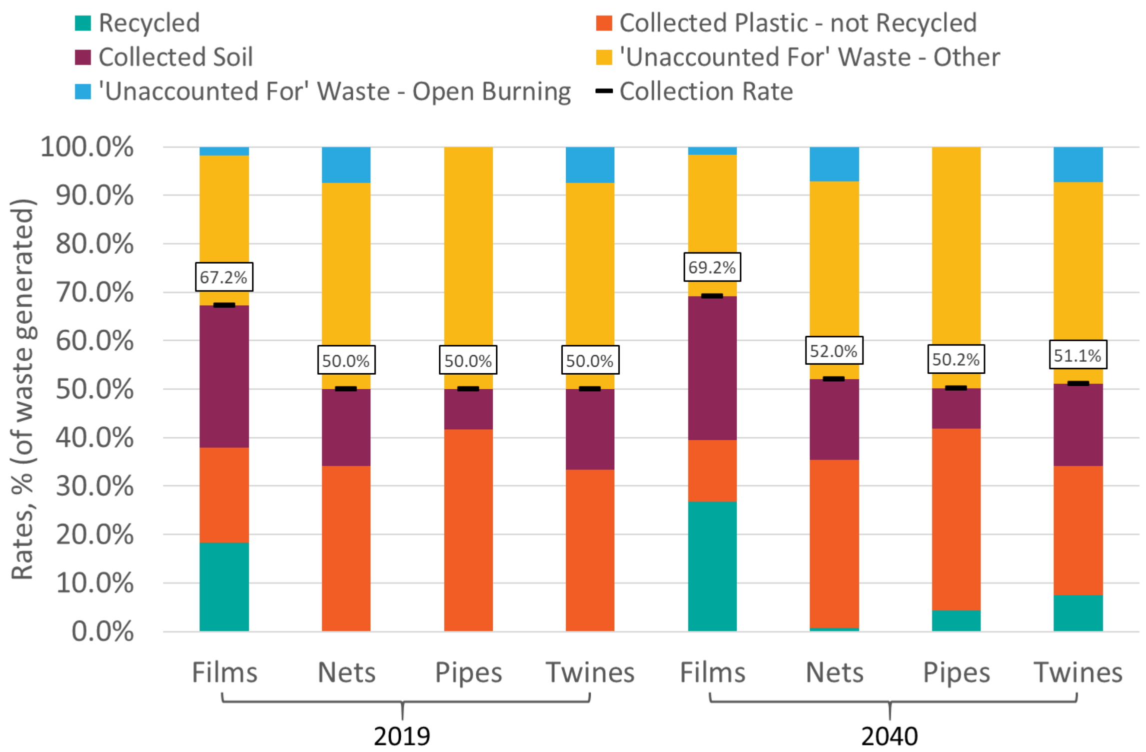
The overall 'yield' of recycled plastic from collected waste is therefore dependent on both the proportion of this waste which is sent for recycling (as opposed to 'direct' residual disposal), and the losses incurred between collection and final recycling at sorting plants and re-processors.

Both these factors vary widely by Member State, collection systems, and waste types. Available data is relatively scarce; current yield rates (i.e. the percentage of collected waste that is recycled) in the baseline are based on values reported by the PRE questionnaire (see Section 2.5.4). These data state that on average 70% of greenhouse films, 50% of silage films, and 30% of stretch films collected in the EU are recycled at present, with negligible recycling of nets, pipes, and twine.

In a similar fashion to collection rates (see Section 5.2), future yield rates are projected based on an assumption that best-practice rates will be achieved within 7 years (mandatory EPR), and within 9 years (voluntary EPR) for Member States with existing or planned national collection schemes. In other words, where existing (or planned) national collection schemes currently send waste directly to residual waste treatment, or to non-optimal sorting and recycling processes, these will be improved so that all collected waste is sent for recycling using best practice sorting and reprocessing processes. The best-practice yield rates are presented in Section A.6.2.3.

The final destinations of waste generated for 2019 (latest year of historic data) and 2040 (final year of projections) are presented in Figure 5-4. Collection rates are shown as a black bar (and remaining waste – in yellow - is 'unaccounted for'). Of this collected waste, the purple fraction is soil (not recycled). Prior to final recycling, further losses of plastic waste are shown in orange. Final waste recycled is shown in green. Please note that this is a recycling rate based on waste generated (including soil), whilst recycling rates quoted in this report are based on recycled plastic as a % of plastic placed on the market (i.e. not including soil in collected waste).

Figure 5-4: Final Waste Destinations, % (2019, 2040)



Recycling rates for plastic are provided in Figure 5-5 and Figure 5-6. As discussed, these are the rate of plastic recycled as a proportion of plastic placed on the market. Overall recycling rates are projected to increase from 24% in 2019 to 36% in 2040.

Figure 5-5: Recycling Rate Projections for the EU28 by Agricultural Plastic Type, % (2019 to 2040)

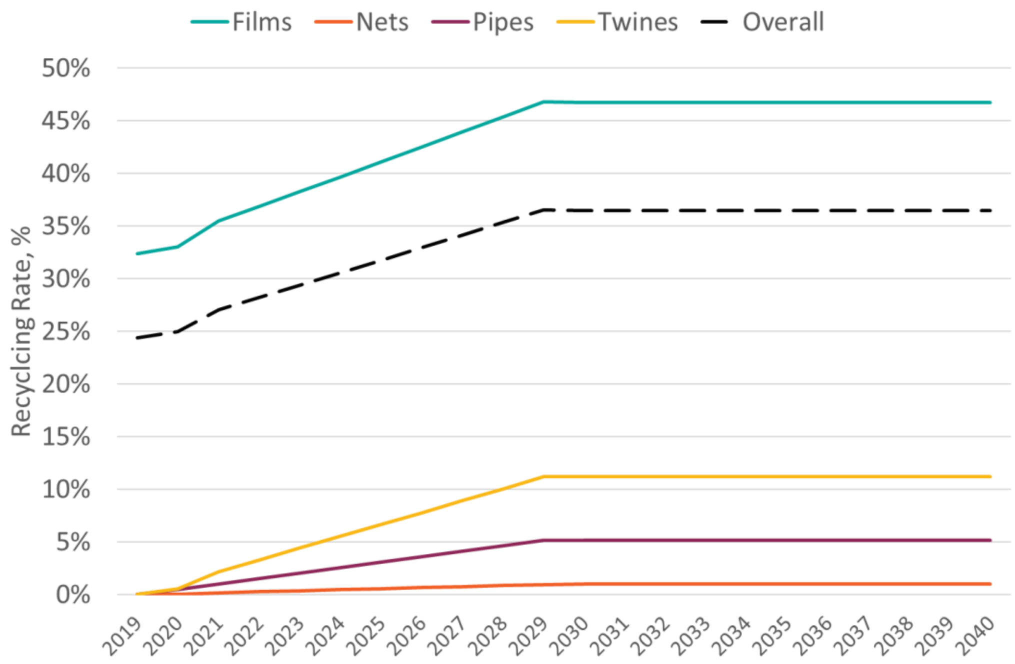
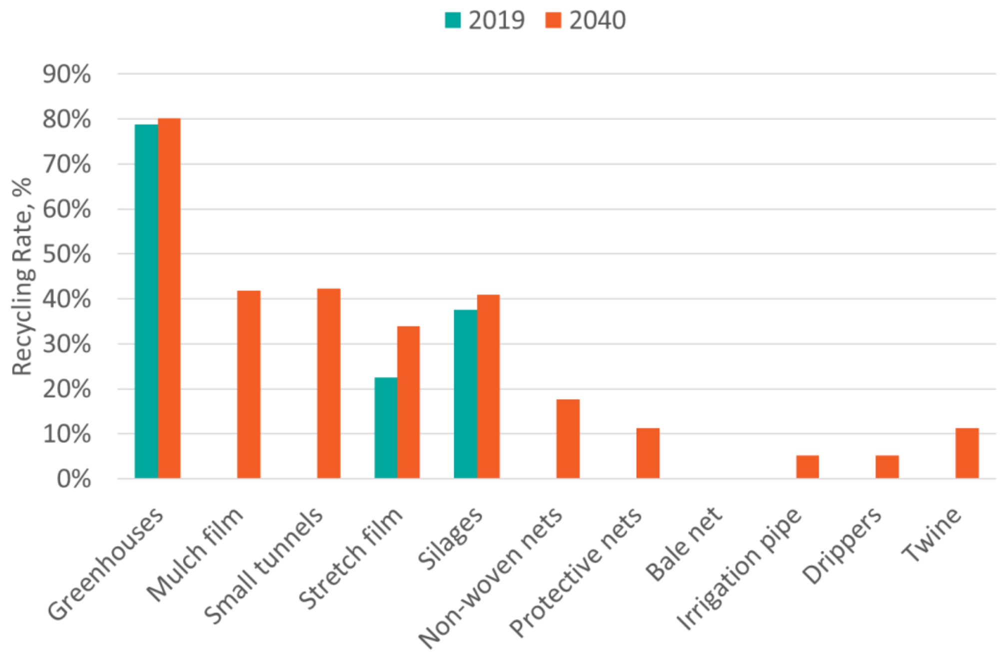


Figure 5-6: Modelled Agricultural Plastics Recycling Rates, % (2019, 2040)



The quantity of waste sent to incineration is projected to decrease in future years. This is based on the assumption that the requirement on Member States, under the Waste Framework Directive (as amended) *"to ensure that waste that has been separately collected…is not incinerated"*, is progressively implemented under existing EPR schemes. The rationale for this modelling assumption is further discussed in Section A.6.2.3.

As the recycling rate increases (see Figure 5-2) , the proportion of waste sent to formalised residual treatment (incineration and landfill) will decrease as material is diverted away from these destinations.

The increase in collection rate leads to diversion of 'unaccounted for' waste to formal waste management systems. This 'unaccounted for' waste includes residual waste treatment of waste collected through local collection schemes, and also disposal routes with a more detrimental environmental impact, such as unmanaged disposal / burning on-site, and waste that is left in the environment. Overall, the net impact is to move waste up the hierarchy. At the 'bottom' of the waste hierarchy there is a modelled shift from waste left in the environment or disposed of through rudimentary disposal routes (buried on site or burnt) to formalised waste management routes. This is in conjunction with an overall increase in the proportion of collected waste that is recycled.

6.0 Identification of Objectives and Policy Measures

6.1 Problem Definition

This report has verified the existence of a problem in terms of how agri-plastics are managed across the EU at their end-of-life. Though a lack of available, reliable and recent data makes it challenging to draw robust quantitative conclusions, it is estimated by APE Europe that only ~64% of agri-plastic non-packaging waste generated in the EU was collected in 2019 (this figure includes soil and any other contaminants, see Section 5.1). Furthermore, despite agri-plastics having a high potential for recycling, only 24% of agriplastics were recycled in 2019 (this is measured as the rate of plastic recycled as a proportion of plastic placed on the market, and excludes contaminants).

It is important to also note that recycling rates vary significantly by type of agri-plastic, with mulch films and bale nets currently not being recycled at all (though a mulch film recycling facility in Spain is being developed).[257] The failure to collect agri-plastics may lead to negative environmental impacts, for example, due to the increased risk of 1) plastic residues accumulating in soil and 2) the open-burning of agri-plastics. It is anticipated that in the absence of further interventions there will be limited growth in collection and recycling of agri-plastics.

6.1.1 Problem Drivers

As stated in Tool #14 of the Better Regulation Toolbox, in order to solve the defined problem, its underlying causes (or "drivers") should be identified.[258] The problem drivers identified throughout the course of this research are restated below.

6.1.1.1 Problem Drivers Relating to Low Collection Rates

- **Insufficient economic and / or regulatory incentives for the separate collection of agri-plastic waste** (by polymer type). Most agri-plastic products – with a few exceptions – do not have a positive value for recyclers, and therefore there is little economic incentive for their collection. Furthermore, though the separate collection of agri-plastic waste is required by law (see Section 2.4), the implementation of this requirement is not sufficient across the EU;

---

[257] Interview with Green World Compounding

[258] *Better Regulation Toolbox*, accessed 11 August 2020, https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

- **Technical characteristics of mulch films may mean it is difficult to completely remove the film from the soil without it tearing** (note, more scientific evidence for this point is required);

And where a collection scheme exists:

- **Insufficient awareness among farmers of schemes in existence;** and
- **Insufficient incentives for farmers to participate in the collection of agri-plastic waste** (for example, farmers may choose to (illegally) burn their agri-plastic waste on site or drip feed into the household waste stream rather than participate in the dedicated collection scheme. This is a particular risk for low volume agri-plastics such as netting and twine).

6.1.1.2 Problem Drivers Relating to Low Recycling Rates

- **High processing costs primarily due to high contamination rates** (a particular issue for mulch films and bale nets, which are not currently recycled)
- **Low value / limited end markets for recyclate**

6.1.1.3 Problem Drivers Relating to BDAPs

- **Risk of inappropriate use of BDAPs** (for example, in contexts where they may not completely biodegrade)

6.2 Objectives

As stated in Tool #16 of the Better Regulation Toolbox *"objectives link the analysis of the problem (and its drivers) to the option for the policy response".*[259] The following section sets out the general and specific objectives formulated based on the identified problem drivers.

6.2.1 General Objectives

The general objectives are the Treaty-based goals which the policy aims to contribute to. Article 191(2) of the Treaty on the Functioning of the European Union (TFEU) states that:[260]

> *Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the **precautionary principle** and on the principles that **preventive action***

[259] *Better Regulation Toolbox*, accessed 11 August 2020, https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

[260] OJEU (2012) Consolidated Version of The Treaty on the Functioning of the European Union, Official Journal of the European Union, 26th October 2012, available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:12012E/TXT&from=EN

should be taken, *that* ***environmental damage should as a priority be rectified at source*** *and that* ***the polluter should pay.***[261]

Accordingly, the general objectives adopted for this study are as follows:

- **To reduce the leakage of agricultural plastics into the environment;**
- **To ensure the use and EOL management of agricultural plastics adheres to the waste hierarchy; and**
- **For the polluter pays principle to be respected in the case of EOL management of agricultural plastics.**

6.2.2 Specific Objectives

The specific objectives set out concretely what the policy intervention is meant to achieve. They should be broad enough to allow consideration of all relevant policy alternatives without prejudging a particular solution. The specific objectives, which are based on the key problem drivers are set out in Table 6-1.

Table 6-1: Specific Objectives

Problem Driver		Specific objective
Collection rates		
Insufficient economic and / or regulatory incentives for the separate collection of agri-plastic waste	1	Ensure sufficient economic and / or regulatory incentives for the operation of separate collection schemes for used agricultural plastics at end of life (split by polymer to enable recycling)
Technical characteristics of mulch films may mean it is difficult to completely remove the film from the soil without it tearing	2	Ensure there is a sufficient financial, regulatory and / or reputational incentive for manufacturers to develop mulch films that do not tear during the removal process Ensure widespread understanding and awareness among farmers about the contexts where biodegradable mulch films offer a more desirable alternative to conventional mulch films
Insufficient awareness among farmers of schemes in existence	3	Ensure widespread awareness among farmers as to the agricultural plastic collection schemes available and the benefits of participating

[261] Emphasis added

Problem Driver		Specific objective
Insufficient incentives for farmers to participate in the collection of agri-plastic waste	4	Ensure there are sufficient financial, regulatory and / or reputational incentives for farmers to participate in agricultural plastic collection schemes
Recycling rates		
High processing costs primarily due to high contamination rates	5	Ensure sufficient financial, regulatory and / or reputational incentives for farmers to remove as much contamination from agricultural plastic waste as possible before collection
Low value / limited end markets for recyclate	6	Ensure sufficient financial, regulatory and / or reputational incentives for producers to include agri-plastic recyclate in the manufacture of new products
BDAPs		
Risk of inappropriate use of BDAPs	7	Ensure sufficient controls in place to avoid negative environmental consequences arising from use of biodegradable plastics in agriculture

6.3 Policy Options

6.3.1 Identification of Policy Measures

Based on the specific objectives, a 'longlist' of potential policy measures were identified (see Table 6-2).

Table 6-2: Longlist of Policy Measures

Policy measures to increase collection and recycling rates of conventional agri-plastics	Applicability	Link to specific objective(s)
Voluntary EPR schemes	All conventional agri-plastics	1, 3, 4, 5
Mandatory EPR schemes	All conventional agri-plastics	1, 3, 4, 5
Obligation for farmers to participate in collection schemes	All conventional agri-plastics	4

Policy measures to increase collection and recycling rates of conventional agri-plastics	Applicability	Link to specific objective(s)
Statistical monitoring of agri-plastics placed on market, collected and recycled	Obligation to provide statistical data of agri-plastics placed on market, collected and recycled	1
Ban on open burning plus enforcement	All conventional agri-plastics	4
Minimum thickness / tensile strength for mulch films	Mulch films	2
Leasing model for greenhouse films	Greenhouse films	1
Tax on virgin plastics production	All conventional agri-plastics	6
Incineration tax or ban	All conventional agri-plastics	N/A
Landfill tax or ban	All conventional agri-plastics	N/A
Encourage the use of alternative materials for greenhouses	Greenhouse films	N/A
Exchange of best practices and education of professionals	All conventional agri-plastics	3
Recycled content targets	All conventional agri-plastics	6
Integration of biodegradable agri-plastics into any prospective EPR scheme (for data collection and monitoring purposes)	Biodegradable agri-plastics	7
Where a standard exists, ensuring only certified biodegradable agri-plastics are used	Biodegradable agri-plastics	7
Make EN 17033 mandatory for all BDMs through new legislation	Biodegradable agri-plastics	7

6.3.2 Screening of Policy Measures

In line with Tool #17 of the Better Regulation Toolbox the longlist of policy measures was screened according to the following criteria:[262]

- Legal feasibility
  - Options must represent the principle of conferral. They should also respect any obligation arising from the EU Treaties (and relevant international agreements) and ensure respect of fundamental rights. Legal obligations incorporated in existing primary or secondary EU legislation may also rule out certain options
- Technical feasibility
  - Technological and technical constraints may not allow for the implementation, monitoring and/or enforcement of theoretical options
- Previous policy choices
  - Certain options may be ruled out by previous Commission policy choices or mandates by EU institutions
- Coherence with other EU policy objectives
  - Certain options may be ruled out early due to poor coherence with other general EU policy objectives
- Effectiveness and efficiency
  - It may already be possible to show that some options would uncontrovertibly achieve a worse cost-benefit balance than some alternatives
- Proportionality
  - Some options may clearly restrict the scope for national decision making over and above what is needed to achieve the objectives satisfactorily
- Political feasibility
  - Options that would clearly fail to garner the necessary political support for legislative adoption and/or implementation could also be discarded
- Relevance
  - When it can be shown that two options are not likely to differ materially in terms of their significant impacts or their distribution, only one should be retained

Where one, or a small number of criteria, clearly precluded a measure from being feasible, these are noted, without then addressing the other criteria. For options that were identified as feasible, such identification was made after the option had been screened against all criteria.

[262] *Better Regulation Toolbox*, accessed 11 August 2020, https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

6.3.2.1 Results of Screening

The results of the screening process are shown in Table 6-3. Three policy measures were rejected for further analysis: leasing model for greenhouse films, a tax on virgin plastic production and making EN 17033 mandatory for all BDMs through new legislation. More detail on the reasons for their screening out is available in Appendix A.8.0. All other policy measures were taken forward and tested with stakeholders at a policy options workshop held in July 2020 and discussed in detail with DG Environment. Each of the selected measures is discussed in turn in the following section of the report.

Table 6-3: Results of Screening of Policy Measures

Policy measures to increase collection and recycling rates of conventional agri-plastics	Applicability	Link to specific objective(s)	Results of screening
Voluntary EPR	All conventional agri-plastics	1, 3, 5	Selected
Mandatory EPR	All conventional agri-plastics	1, 3, 5	Selected
Obligation for farmers to participate in collection schemes	All conventional agri-plastics	4	Selected
Statistical monitoring of agri-plastics placed on market, collected and recycled	All agri-plastics	1	Incorporated into EPR measure (see Section 7.1)
Ban on open burning plus enforcement	All conventional agri-plastics	4	Selected
Minimum thickness / tensile strength for mulch films	Mulch films	2	Selected
Leasing model for greenhouse films	Greenhouse films	1	Rejected
Tax on virgin plastics production	All conventional agri-plastics	6	Rejected

Policy measures to increase collection and recycling rates of conventional agri-plastics	Applicability	Link to specific objective(s)	Results of screening
Integration of biodegradable agri-plastics into any prospective EPR scheme (for data collection and monitoring purposes)	Biodegradable agri-plastics	7	Selected
Where a standard exists, ensuring only certified biodegradable agri-plastics are used	Biodegradable agri-plastics	7	Selected
Make EN 17033 mandatory for all BDMs through new legislation	Biodegradable agri-plastics	7	Incorporated into EPR measure (see Section 7.3)

7.0 Discussion of Selected Policy Measures

7.1 Extended Producer Responsibility

Extended Producer Responsibility (EPR) is a policy approach which Member States could use to ensure the separate collection, and subsequent recycling, of agri-plastics is achieved. As noted in Section 2.4, there is a requirement under the revised WFD to separately collect plastics. Article 11(1) states that:

> *"Member States shall take measures to promote high quality recycling and, to this end, shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors. Subject to Article 10(2), by 2015 separate collection shall be set up for at least the following: paper, metal, plastic and glass."*

Given that there is nothing in the WFD to indicate that this requirement is limited to a particular type of plastic waste, our interpretation is that it applies to all plastic waste, including agri-plastic waste. However, Member States appear to have largely ignored this requirement in terms of its application to agri-plastics; for example, there are a number of Member States where the separate collection of agri-plastics is left up to the free market, and therefore does not occur.

Under EPR, producers have responsibility – financial and/or operational – for the end-of-life management of post-consumer products. If an agri-plastic EPR scheme was to be set up, producers would be responsible for ensuring logistics for the separate collection of agri-plastics are in place. They would also be responsible for ensuring the collected waste is managed in line with the waste hierarchy. It should be noted that agri-plastic EPR schemes are already in place in some Member States (see Table 2-4).

Furthermore, EPR would help address the following specific objectives, depending on the scheme design:

- **Ensure sufficient economic and / or regulatory incentives for the operation of separate collection schemes for used agricultural conventional plastics at end of life** – EPR provides a regulatory incentive for the operation of such collection schemes.
- **Ensure widespread understanding and awareness among farmers as to the agricultural plastic collection schemes available and the benefits of participating** – an EPR scheme is likely to involve significant awareness raising and marketing efforts to ensure it achieves its target collection rate.
- **Ensure sufficient financial, regulatory and / or reputational incentives for farmers to remove as much contamination from agricultural plastic waste before collection** – an EPR scheme would be highly likely to incorporate a mechanism to incentivise farmers to reduce contamination in the agri-plastic

waste delivered to the scheme, as high levels of contamination increase the cost of transport and EOL treatment, and therefore influence the producer levy.

- **Ensure sufficient financial, regulatory and / or reputational incentives for agricultural plastic producers to include agri-plastic recyclate in the manufacture of new products (i.e. closed loop recycling) –** an EPR scheme could incorporate fee modulation which encourages the incorporation of recyclate in agri-plastic products.

We consider three potential policy approaches for implementing EPR for agri-plastics: mandatory EPR; voluntary EPR (incentivised); and voluntary EPR (non-incentivised). These are discussed in more detail in the following sections.

7.1.1 Mandatory EPR

Mandatory EPR is the strongest EPR policy approach, and the only approach guaranteed to ensure EPR schemes are set up in all Member States. Under this option, a legislative requirement would be placed on agri-plastics producers to fund the EOL management of products they place on the market. The legislation could go further than this and shape the nature of the scheme by requiring that specific design principles are implemented and targets are met. We would suggest the following requirements:

- **A minimum collection rate target for agri-plastics**: Not all existing EPR schemes have an explicit collection rate target, but where targets exist, they are in the range of 65% – 70% (as an average across all agri-plastics within the scheme scope) (see Table 7-1). It is possible that higher collection rates can be achieved (for example, SvepRetur estimates that in 2018, ~92.5% of the total agri-plastics, including packaging, placed on the Swedish market were collected). By contrast, a representative from ERDE stated that a collection target of 70 – 75% is the maximum feasible limit for both mandatory and voluntary schemes, and a representative from IFFPG suggesting it would be very challenging to increase collection rates beyond 80%.[263] ADIVALOR is more optimistic, with a representative suggesting collection rates of 90% are a realistic maximum (some farmers will always choose to use other routes to dispose of agri-plastic waste e.g. municipal waste centres).[264]
- **Minimum coverage requirements**: to support a high collection rate, there should be a requirement to ensure that all farmers have adequate access to a convenient collection service. This was part of the agreement when the French scheme was being set-up.
- **A minimum recycling rate target for agri-plastics:** a recycling rate target provides an incentive to focus on quality in terms of the agri-plastics collected, and can

[263] Interviews with ERDE, IFFPG and SvepRetur
[264] Interview with ADIVALOR

stimulate investment to ensure the target is met. . Recycling rate targets could be initially based on what is being achieved in existing agri-plastic EPR schemes.

Table 7-1: Existing EPR Schemes - Collection & Recycling Rate Targets

Scheme	Collection rate target	Recycling rate target
IFFPG (Ireland)[265]	70% for silage wrap & sheeting	N/A
ADIVALOR (France)[266]	80% for agri-films; 55% for nets & twines	84% for agri-films; 50% for nets & twines (of collected material)
ERDE (Germany)[267]	65% for silage wrap & sheeting by 2022	All silage wrap & sheeting collected by the scheme is recycled
SvepRetur (Sweden)[268]	70%	30% (of collected material)

- **Minimum data requirements:** In order to report against recycling rate and collection rate targets, producers will by default need to collect data on the tonnage of agri-plastics placed on the market, the tonnage collected, and the tonnage recycled.[269] A robust methodology for accurately determining the level of contamination in collected plastics will need to be applied by each scheme. However, it is suggested that beyond this, legislation for mandatory EPR could also place a requirement on producers to collect the following data:

    - the volume / type of agri-plastics sold to each individual farm; and,
    - the volume and type of agri-plastics returned by each farm.

  This level of insight would allow the identification of farmers who have purchased agri-plastics but who have not returned them via the EPR scheme. The data could therefore potentially support other policy measures (e.g. a requirement for

[265] Interview with IFFPG
[266] Accord-cadre pour la periode 2016 -2020
[267] Interview with ERDE
[268] Interview with SvepRetur
[269] While in principle the requirement for detailed data collection could be a standalone measure, it seems unlikely to be implemented in the absence of efforts to increase collection, given the legal requirement for separate collection. In line with the polluter pays principle, some form of EPR would be desirable, and hence the data requirements are discussed in the context of EPR.

farmers to participate in an agri-plastics collection scheme or a ban on open burning of agri-plastics). It is important to note that feedback from stakeholders in the policy options workshop suggested that collecting data on the volume and type of agri-plastics sold to each individual farm may be challenging. It would require retailer co-operation, and there are complexities in the supply chain which may make tracing certain types of agri-plastics more difficult, for example, silage wrap can be provided by contractors as part of a service, rather than purchased directly by farmers. However, better data is at the heart of the move towards a circular economy, and in the case of an agri-plastics EPR scheme, having such data would significantly enhance the ability to understand and enhance scheme performance. Even if an EPR scheme is not introduced, there is still a need for a statistical monitoring of agri-plastics placed on market, collected and recycled as a stand-alone measure.

- **Best practice guidance (optional):** Best practice guidance could be published alongside the mandatory EPR legislation. This guidance would outline design principles that a best-practice EPR scheme should follow in order to maximize collection rates of clean material, for example:
    - **Producer fees fully cover net EOL costs:** If the producer fee fully covers the net EOL costs, there is no need for farmers to have to supplement the producer fee with a contribution at the point of collection. This is beneficial because any charge at the point of collection may act as a financial disincentive for farmers to return agri-plastics via the scheme.
    - **Mechanism to reduce contamination:** Farmers should be incentivised in some way to reduce contamination in returned agri-plastics. For example, one option is a rebate-style system whereby the cost of an assumed level of contamination is included in the producer fee (e.g. ~50%), and farmers receive a rebate if they deliver plastics with a contamination rate below that threshold.
    - **Fair allocation of EOL costs:** Producer levies should vary by product type to reflect variation in EOL costs for different types of agri-plastics. This approach avoids producers who sell one type of agri-plastic subsidising the cost of managing other types of agri-plastics.
    - **Communication / education:** The EPR scheme should develop a strategy to communicate best practices for removing, storing and arranging for the collection of agri-plastics with famers. For example, this should include measures that can be taken to reduce contamination (e.g. removal during a dry period if possible, storage inside).
    - For more detail on the design principles that a best-practice EPR scheme should follow, please refer to Appendix A.9.0.

7.1.2 Voluntary EPR (incentivised)

An alternative approach to mandatory EPR is to incentivise the set-up of voluntary EPR through the provision of funding. This approach would not require any legislative changes. It’s important to note that without legislative changes, there would be no way of creating legally binding recycling rate or collection rate targets. Nor would there be minimum coverage or data requirements. However, all these elements could be voluntarily agreed with national governments (For example, there is a framework agreement between ADIVALOR and the French government which includes collection and recycling rate targets).

APE Europe suggests that funding could be used to support the set-up and launch phases of an agri-plastics EPR scheme (e.g. preliminary study, pilot operations, communications with stakeholders etc.). Initial suggestions are that approximately €200k - €300k per year for two to three years would be required for a country of similar scale to France or the UK.[270]

7.1.3 Voluntary EPR (non-incentivised)

A final option is for the European Commission to release a communication which strongly encourages Member States to set up an EPR scheme for agri-plastics. This communication would highlight the need to manage agri-plastic waste effectively across the EU, highlighting the requirement for separate collection of plastics under the WFD. It would outline the advantages of a national EPR scheme, for example, cost-effectiveness, and adherence to the polluter pays and precautionary principles which underpin EU environmental law.

7.1.4 Voluntary vs. Mandatory EPR

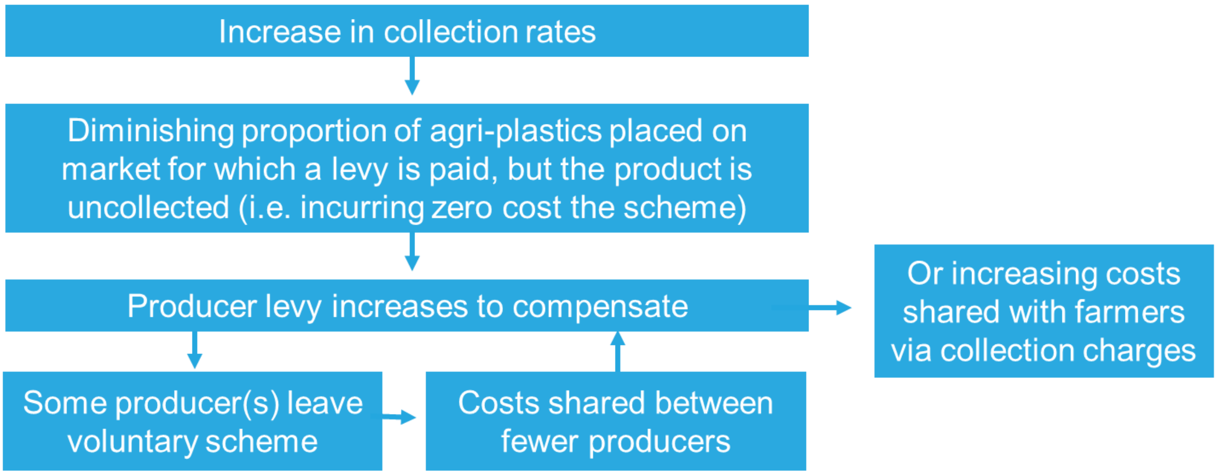
Given there are a range of options available in terms of how EPR could be implemented, it is useful to compare mandatory vs. voluntary approaches, and draw out the relative strengths and weaknesses of each. Based on a review of the dynamics of existing agri-plastic EPR schemes, we present the below analysis.

Stability of Schemes at High Collection Rates

Voluntary schemes have demonstrated performance up to a certain level of collection (e.g. ADIVALOR in France achieved ~67% average collection rates in 2019).[271] However, we suggest that voluntary schemes have the potential to become unstable at very high collection rates. This is due to the dynamics outlined in Figure 7-1 and explained further below.

[270] Interview with APE Europe
[271] Data provided by ADIVALOR

Figure 7-1: Dynamics of Voluntary EPR Schemes at High Collection Rates



The producer levy paid on uncollected agri-plastic products subsidises the EOL costs of collected products. As collection rates rise and a smaller proportion of products are uncollected, producer levies are likely to need to be adjusted upwards to become closer in line with true EOL costs per tonne (or alternatively, farmer collection costs may be introduced / increased). As collection rates increase, there may be some scheme savings associated with economies of scale (e.g. more agri-plastic passing through a scheme-owned pre-treatment plant). However, this depends in part upon how the increased tonnages are arrived at. If the number of bring centres remain fixed and the tonnages delivered to them increases then the fixed costs of operating the bring centres will be shared among a higher tonnage of material. However, it may also be necessary to open further bring centres in order to reach collection goals.

To illustrate this concept, in Ireland the producer levy for netting & twine products is €140 per tonne. The scheme is mandatory, and this levy is paid on all netting & twine products placed on the market. The EOL costs for netting and twine are higher than this on a per tonne basis. However, currently only ~18% of the netting and twine placed on the market is collected by the IFFPG scheme. Therefore, there is sufficient income from the producer levy and farmer collection charge (an additional €10 per tonne) to cover the costs of collection and treatment for the returned material. If netting and twine collection rates were to increase, the current funding model would not be sufficient to cover EOL costs (the producer fee or farmer collection charge – or both – would need to increase).

In theory, as collection rates increase, there may come a point when producer fees are high enough to trigger one or more producers to leave a voluntary scheme. If this were to happen, the total EOL costs of all the collected material would then be shared between fewer producers, and the producer levy per tonne placed on the market would need to further increase. (Note here that once an agri-plastic product has been purchased and used, it is often not possible to identify which producer it came from, and therefore whether or not a levy has been paid – so even if a producer dropped out of the scheme, it is highly likely that its products would continue to be returned via the scheme and the costs borne by the participating producers). There is a risk that if this cycle continued, a voluntary scheme may become financially unstable at high collection rates. This risk does not exist under a mandatory scheme because there is no option for producers to choose to leave the scheme.

Farmer Collection Fees under a Voluntary Scheme

In some existing agri-plastic EPR schemes producer levies do not cover the full net costs of EOL management and must be supplemented by a weight-based contribution at the point of collection (see Table A9.1). One of the core drivers of this is the desire to avoid producer levies being high enough to dissuade producers from participating in a voluntary scheme. This is the case in the French scheme, where the producer levy for mulch films / flat sheets is not set at a level to reflect the true EOL costs due to concerns that doing so could make the risk of free-riding too high. To make up the shortfall in funding, farmers must make a contribution of €155 per tonne of mulch film / flat sheeting at the point of collection. The scheme is gradually increasing the producer levy for mulch film / flat sheeting over time, with the objective of covering the full net costs of EOL up front.

Charging collection fees to farmers does not align with EPR best practice; full net costs of EOL should be covered up front. There is a risk that charges at the point of collection could act as a disincentive for farmers to return their agri-plastics via the scheme, and possibly encourage mismanagement (e.g. burning agri-plastics on site). One benefit of a mandatory scheme, therefore, is that there is less need to consider balancing EOL costs between producer levies and farmer collection fees in order to ensure the levy is palatable to participating producers.

Contamination-Rebate

Ensuring sufficient incentives for farmers to remove contamination from agri-plastic waste before collection is one of the specific objectives identified as part of this project. Although it is considered better EPR design to avoid a charge at the point of collection, a weight-based charge *does* act as an incentive for farmers to reduce contamination in returned agri-plastics.

An alternative worth exploring is whether a rebate-style system could be implemented whereby the cost of an assumed level of contamination is included in the up-front producer levy, and farmers receive a rebate if they deliver plastics with a contamination rate below that threshold. This mechanism does not require farmers to pay any fee at the point of collection, and in fact could incentivise farmer participation (as the farmer has a chance of receiving a rebate if they return their plastics with a low level of contamination). The complication is that it is very difficult to visually assess the rate of contamination of any agri-plastics (e.g. film heavily contaminated with moisture would appear clean) so some level of scientific analysis would be required, at an additional cost.

ADIVALOR operates a system whereby such an analysis for mulch films can take place. It places the onus on farmers to request a scientific analysis if they believe their agri-plastics to be below the contamination threshold. If the results show this is the case, the

EPR scheme covers the cost of the analysis (and a discounted collection charge is applied), but if not, then farmers are liable for the cost of the analysis.

Confidence to Investors

Mandatory EPR schemes provide confidence to investors in recycling facilities, as there is a guaranteed supply of plastic feedstock in future years. One of the key challenges for existing agri-plastic EPR schemes is finding recyclers for the collected material. There is limited capacity for plastic recycling in Europe, and recyclers typically prefer cleaner commercial and industrial plastics. A guaranteed supply of agri-plastics may help to encourage investment in additional plastic recycling capacity in Europe.

Fee Modulation

Fee modulation can be applied within an EPR system; under a modulated fee approach, the fees paid by producers vary according to specific criteria relating to aspects of their products' environmental performance. The idea is that those products that perform well against certain criteria are charged at a lower rate, and those that perform poorly may have a penalty applied. Given the need to stimulate demand for recyclate, recycled content could be an appropriate criteria for modulation in an agri-plastics EPR scheme (indeed, this is being considered by IFFPG in Ireland). Note though, that a modulation structure which incentivises the incorporation of recycled content would not necessarily stimulate demand for *agri-plastic* recyclate (the recycled content could be sourced from other types of plastic).

It may be necessary to modulate strongly in order to incentivise a particular change. This is easier to do under mandatory scheme, because under a voluntary scheme producers who incur a penalty may be at risk of leaving the scheme.

Mandatory Data Collection

EPR schemes can require producers to provide data. As a minimum, all EPR schemes (whether voluntary or mandatory) must require producers to share data on the tonnage of agri-plastics placed on the market and must collect data on the tonnages collected and recycled. This is to allow the performance of the scheme to be monitored. EPR schemes could go further than this and require more detailed information, for example:

- Agri-plastics sold to each individual farm; and
- Agri-plastics returned by each individual farm.

Under a mandatory scheme, comprehensive data collection requirements can be written into legislation, so producers have no choice but to comply. In comparison, comprehensive data collection requirements may act as a barrier to participation in a voluntary scheme (assuming that producers and other stakeholders in a voluntary scheme would want the least onerous data collection requirements possible). Furthermore, there are likely to be limited sanctions available under a voluntary scheme to take action against producers who fail to provide the required data.

Level Playing Field

Mandatory EPR schemes guarantee a 'level playing field' for all producers. The cost of managing agri-plastics at their EOL are shared fairly between all producers as there is minimal opportunity for free-riders, unlike in a voluntary scheme.

Box 7-1: Strengths of a Mandatory Agri-plastic EPR Scheme

In summary, we propose that there are a number of advantages associated with a mandatory agri-plastic EPR scheme, when compared to a voluntary approach:

- Mandatory schemes are likely to be more stable than voluntary schemes at the very highest collection rates
- Under a mandatory scheme there is less need to manage the risk of free-riders, and thus full costs can more readily be incorporated into the price of agri-plastics, meaning farmers are not required to pay collection fees
- Mandatory schemes provide more confidence to investors in recycling facilities that there will be a continued supply of feedstock material in future years
- Mandatory schemes provide a more stable platform for the collection of comprehensive, and complete, data on the use and return of agri-plastics
- Mandatory schemes guarantee a level playing field for all producers

Transition from Voluntary to Mandatory

Having outlined the strengths of a mandatory approach to EPR, it is important to also note that voluntary schemes have demonstrated strong performance up to a certain level (most notably the French scheme ADIVALOR and the Swedish scheme SvepRetur). If a voluntary approach to EPR is adopted in the first instance, it does not preclude a transition to a mandatory EPR, or the introduction of legally binding recycling and collection rate targets at a later stage. Such a transition may be appropriate if a voluntary approach does not achieve the desired level of performance.

7.2 Complementary Measures that Enhance the Effect EPR

7.2.1 Obligation on Farmers to Participate in an Agri-plastics Collection Scheme

This measure is a requirement placed on farmers to participate in an agri-plastics collection scheme. This should be a collection scheme which:

- collects agri-plastics separately from other materials (i.e. not a commercial residual waste collection scheme); and,
- adheres to the waste hierarchy (i.e. recycles agri-plastics where feasible).

This measure would help achieve the following specific policy objective:

- Ensure there are sufficient financial, regulatory and / or reputational incentives for farmers to participate in agricultural plastic collection schemes.

It is envisaged that this measure is used in combination with mandatory EPR to encourage high farmer participation rates in a mandatory scheme and in turn drive higher collection rates. Combining this measure with a voluntary EPR scheme may be problematic, due to the dynamics outlined in Figure 7-1. As farmer participation drives up collection rates, there is a risk of the voluntary scheme becoming unstable.

Feedback from the policy options workshop was that it is preferable to place responsibility on *producers* to manage agri-plastic waste appropriately, as opposed to placing this responsibility directly onto farmers. Farmers already feel they are heavily regulated, and any legislation that makes it mandatory for farmers to participate in a collection scheme is likely to be resented and resisted by farmers who will view it as another restriction or cost imposed on their business. However, it is suggested that this measure is used in combination with mandatory EPR, which would mean all farmers have adequate access to an agri-plastic collection scheme, thus minimising the burden of a requirement to participate.

7.2.2 Ban on Open Burning + Enforcement

This measure is a ban on open burning of agri-plastics combined with effective enforcement. It would help address the following specific policy objective:

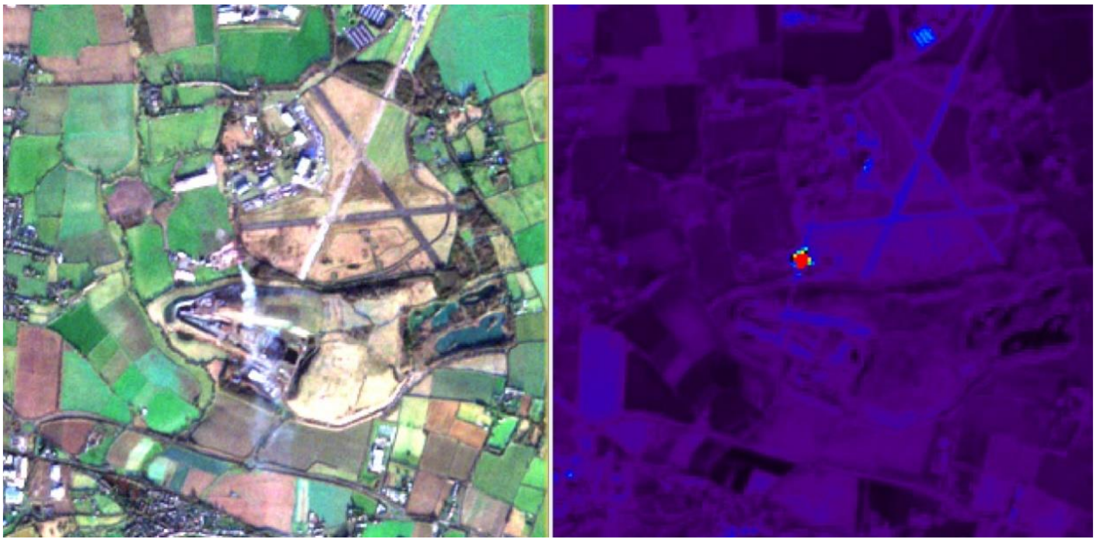
- Ensure there are sufficient financial, regulatory and / or reputational incentives for farmers to participate in agricultural plastic collection schemes.

A number of member states already have policies in place which ban the burning of agricultural plastics / agricultural waste (see Table 2-3). However, evidence (albeit limited) suggests that such bans are not always effectively enforced. – It is understood that this is because before taking enforcement action regulators need to actually observe the practice taking place, which in reality is very difficult to do.

Under this policy measure, it is suggested that satellite data is used to help enforce a ban on open burning of agri-plastics. Initial discussions with remote sensing experts suggest that it may be possible to identify ‘burn’ sites on agricultural land from satellite imagery (i.e. by using a combination of smoke plume and thermal anomaly detection) (see Figure 7-2).[272] However, further proof of concept / a pilot project would be required to confirm the results that could be achieved from using satellite imagery.

[272] Communication with 4 Earth Intelligence and Air & Space Evidence

Figure 7-2: Example of Satellite Imagery – Burn Event on a Farm



Source: Air & Space Evidence

Using satellite imagery to detect burn sites across all agricultural land in Europe would be expensive to implement; if commercial satellite imagery was required, costs could reach into the millions of Euros per year. The volume of burn sites detected may also be too high to be helpful in terms of targeting enforcement, especially if legal burning of vegetation etc. is also taking place on agricultural land.

Therefore, it is suggested that it could be more effective to be selective in terms of the satellite imagery analysed for burn events. For example, if an EPR scheme implemented a comprehensive data management system whereby it recorded the agri-plastics purchased by individual farmers, and the agri-plastics returned by individual farmers, it would be possible to identify farmers who may not be returning their used agri-plastics. These farmers are at a higher risk of burning plastics on-site. This information could then be used to check particular locations for evidence of burning (via satellite imagery). A few high profile incidents of satellite imagery being used to enforce a ban on burning of agri-plastics may be effective in reducing the prevalence of such behaviour. If this approach was implemented regulators would remain responsible for enforcing a ban on open burning of agri-plastics, but EPR schemes would be required to provide the relevant data to the authorities. This measure has been taken forward for modelling in combination with mandatory EPR (as the comprehensive data collection that is required to support this measure is likely to be difficult to implement under a voluntary EPR approach).

It should also be noted that satellite imagery which identifies burn sites would have a broader application than just identifying the burning of agri-plastics. For example, such data could also be used to help identify other types of waste crime. There therefore may be scope to share the costs of obtaining and analysing such satellite data with other applications.

7.3 Biodegradable Agri-Plastic Policy Measures

Two of the policy measures selected specifically relate to biodegradable agri-plastics (BDAP) and achieving the following specific objective:

- ensure sufficient controls are in place to avoid negative environmental consequences arising from the use of BDAPs in agriculture.

Two policy measures designed to address this objective are proposed, though these are not modelled separately, as they are measures aimed at supporting the appropriate use of BDAPs by providing a framework for producers to verify claims. This would allow growers to choose the appropriate product for their needs. The measures are also cross cutting and should be considered as integral to all of the EPR policy measures.

7.3.1 The Integration of Biodegradable Agri-plastics into EPR Scheme

The first step to achieving the specific objective is to have a good understanding of how and where BDAPs are used. This measure aims to achieve this through the integration of BDAPs into EPR schemes. The EPR scheme would require BDAP producers to provide at least the following data for products placed on the market: mass, hectare coverage, farm location and crop. In reality, the farmer would have to supply this information at the point of sale – so the EPR data collection system would need to be adapted to incorporate this data. BDAP producers would be exempt from contributing to collection and EOL treatment costs (as there are none associated with biodegradable agri-plastics), but a small data management fee would apply.

In order for this policy measure to be effective, the EPR scheme in question would need to have full producer participation and strong data collection requirements – most easily achievable under a mandatory approach. This policy measure is likely to be less effective under a voluntary EPR approach as BDAP producers could simply choose not to participate or share the requested data. As this measure would form an element of a mandatory EPR scheme, it has not been costed separately in the modelling phase of this work (there would likely be a small additional cost associated with setting up an appropriate data collection system, but this is not significant).

During stakeholder discussions, producers of BDAPs were broadly supportive of this proposed measure, as being integrated in any EPR scheme alongside conventional agri-plastics was viewed positively by the industry.

7.3.2 Ensuring only certified BDM products are used

The risk of products being incorrectly labelled as biodegradable may increase in the event that EPR schemes are introduced and producer fees do not apply to biodegradable products. Ensuring only certified biodegradable products are used would minimise the risk of products being misleadingly marketed as biodegradable, and potentially failing to degrade appropriately in the soil. Currently, the only standard that exists for BDAPs is aimed at mulch films (EN 17033). As such there is currently no justification (or ability to verify) an exemption from EPR fees for other BDAP product types.

One way of implementing this measure is to require producers of BDAPs to participate in EPR schemes (as above), but only exempt certified BDAP products from full payment (where an agreed standard exists). Producers of uncertified products would be required to pay the same producer fee applied to conventional agri-plastics. Again, this measure would be most effective when combined with a mandatory EPR scheme (under a voluntary scheme, BDAP producers could simply choose not to participate).

If the current EN 17033 is to be referenced in EPR schemes as evidence of conformance and exemption from EPR disposal costs it should also be revised to reflect best practice and uncertainty. Currently the Standard suggest that growers incorporate the material into soil after the growing period. This may not be possible (or typical practice) for some crops (e.g. vineyards) and therefore this practice is not always observed. It is recommended that no exemption is given to any crop type where the grower cannot provide evidence that soil incorporation is taking place.

For mulch films and other BDAPs that remain on the soil surface a new Standard and associated test method will have to be developed in order to provide a framework to allow such products to benefit from EPR exemptions. Furthermore, BDAP products that do not have a verified and accepted Standard associated with them should be considered as 'mismanaged' if left in the environment in the same way as conventional plastics are currently.

7.4 Minimum Thickness / Tensile Strength for Conventional Mulch Films

Expert opinion (see 3.1.1) suggests that the thinner the mulch film, the more likely it is to tear when being removed from the soil which can lead to plastic fragments that remain in the environment and accumulate in agricultural soils. One of the policy measures selected is a mandatory minimum thickness for conventional mulch films to minimise the risk of tearing during the removal process. This should also be paired with a minimum tensile yield strength as this is the important material property that will define the necessary thickness i.e. a material at a given thickness will tear easier if it has a lower tensile yield strength. In this case, it is important that material properties are not sacrificed.

It was highlighted in the policy options workshop that a **thicker** film may better allow the integration of recycled content, and also, that as a proportion of the material being recovered, contamination would be lower (a thicker film would mean an increase in the plastic:soil ratio). Both of these aspects would be key steps towards developing a market for recycling of conventional mulch films.

A mandatory minimum thickness / tensile strength for conventional mulch films could minimise the risk of tearing during the removal process (and plastic fragments subsequently accumulating in the environment). Currently, there is very limited quantitative evidence available to link specific mulch film thicknesses to the proportion of plastic remaining in the environment post-removal.

Currently, there is very limited quantitative evidence available to link specific mulch film thicknesses to the proportion of plastic remaining in the environment post-removal. The European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) specifies that for black mulch films the minimum thickness should be 20 - 25µm. However, the standard is not mandatory and the proportion of mulch film products that comply with the standard is not known.

It is therefore recommended that further research is conducted to better understand this relationship before any mandatory minimum thickness (or strength) is recommended.

This research should include:

- In field testing of the level of recovery achievable for mulch films of different thicknesses used in different crop types and whether optimal conditions exist (e.g. dry or wet days) for this.
- Testing and identification of the best practice for mulch film recovery from the field including the use of specialised mechanical equipment
- Testing of the recovered material for soil contamination and recycling to determine whether recyclers are more likely to find thicker films economically viable to recycle and the implications of this on incorporating closed-loop recycled content.

Due to the uncertainty around the effectiveness of this measure with regard to the increase in recycling rates, this policy measure has therefore not been taken forward for modelling.

7.5 Summary of Policy Measures Taken Forward for Modelling

In summary, the following policy options have been taken forward for modelling:

- Voluntary EPR (non-incentivised)
- Voluntary EPR (incentivised)
- Mandatory EPR for producers
- Mandatory EPR + ban on open burning and enforcement
- Mandatory EPR + requirement on farmers to participate in an agri-plastics collection scheme

8.0 Modelled Performance of Different Policy Measures

This section summarises the impacts of the modelled policy measures and compares these to the baseline (business as usual). These impacts include the change in flows of plastic agricultural products, a breakdown of changes in financial costs for producers and farmers, and an overview of environmental benefits achieved.

The policy measures modelled, as defined through the work described in Section 6.0 and 7.0, are presented in Table 8-1 which summarises the main modelling parameters for each measure.

Table 8-1: Modelled Policy Measures and Model Parameters

	Voluntary EPR (non-incentivised)	Voluntary EPR (incentivised)	Mandatory EPR	Mandatory EPR + ban on open burning	Mandatory EPR + participation requirement
Expected Collection Rate, %	70%	70%	80%	82%[1]	95%
EPR Scheme Start Date	2026	2024	2023	2023	2023
Expected Collection Rate Achieved	2035	2033	2030	2030	2030

Notes:

1. ***This additional collection (relative to the 'Mandatory EPR' option) is achieved by diversion of waste which was previously burnt to formal waste collection.***

A detailed methodology for scenario modelling is described in A.7.2, although the reader should be aware of a few key components of the rationale applied:

- Modelled EPR schemes are assumed to cover the full range of agricultural plastic applications, and existing EPR schemes are assumed to expand in scope to meet this full coverage at the same time as modelled schemes are implemented.

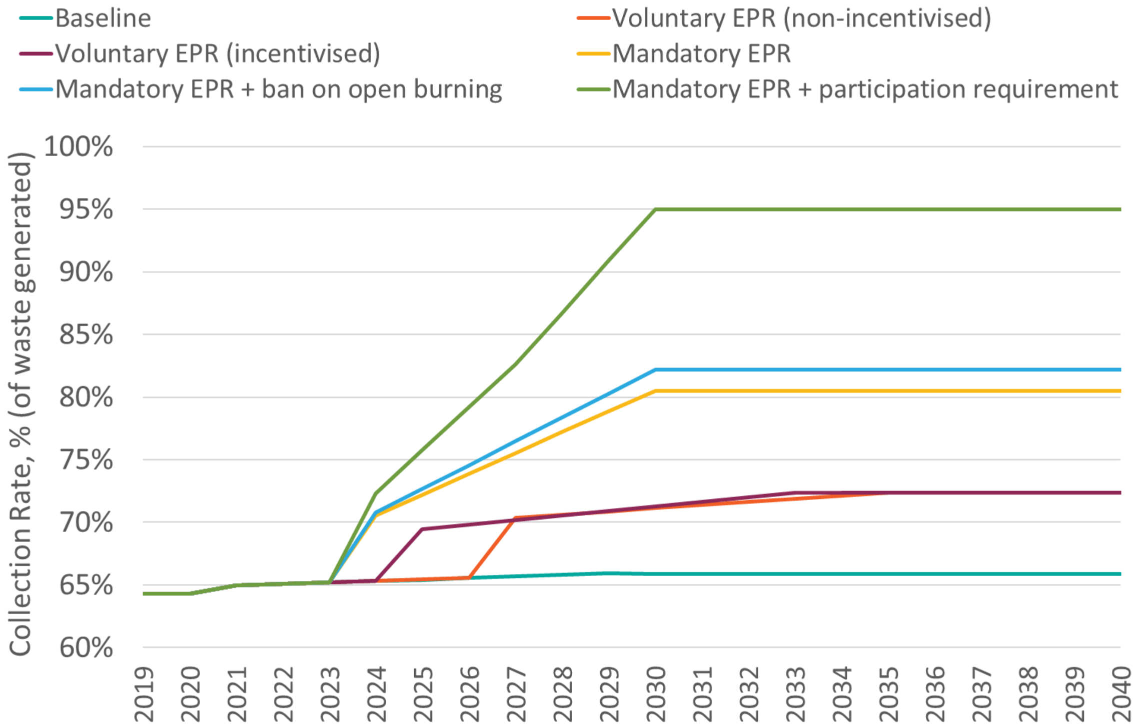
- The EPR scheme start date is the year of implementation of the scheme, it is assumed that any benefits (on collection rate, financial costs etc.) begin in the following year.
- Existing schemes are never switched from being mandatory to voluntary, i.e. if a voluntary EPR policy measure is modelled, any existing mandatory schemes will continue.
- Other model parameters remain constant relative to the baseline – waste projections, loss rate assumptions and assumed impacts of existing policy on residual waste treatment (see Section 5.0).

The modelled impacts are presented in the following sections.

8.1 Impacts on Waste Management

An overview of modelled separate collection rates for the baseline and all policy measures is shown in Figure 8-1. These show the trajectory of collection rates to meet the best-practice collection rate 'targets' detailed in Table 8-1.

Figure 8-1: Modelled Collection Rates (2019 to 2040), %



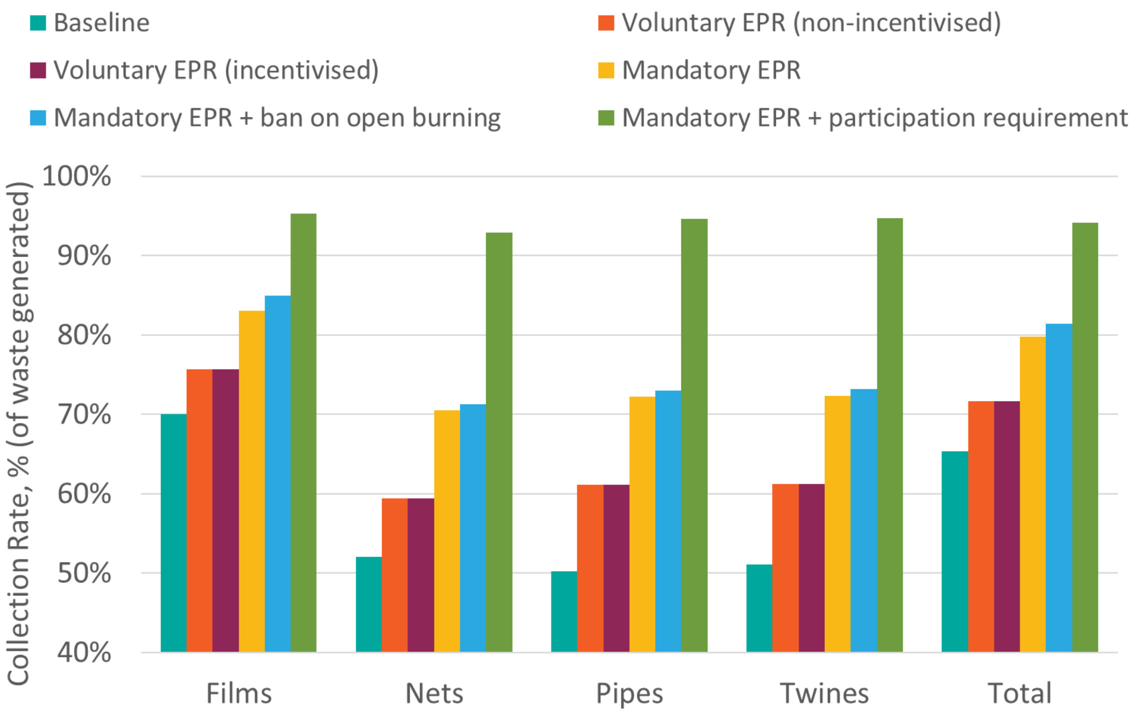
After the modelled EPR schemes have taken their full effect, modelled collection rates exceed the expected collection rate (see Table 8-1) for all measures bar the *mandatory EPR + participation requirement* measure. This is a consequence of the relatively high average performance of existing mandatory schemes (>80% collection rate) which exceed the expected collection rate for nearly all policy measures modelled. As any mandatory schemes in the baseline are modelled to continue and expand in scope in conjunction with the implementation of new EPR schemes (see Section 8.0), this has the impact, as shown, of pushing the final collection rates slightly above the expected collection rates for new schemes (with the exception of *mandatory EPR + participation requirement)*.

This figure also demonstrates the impact of the increased scope of modelled EPR schemes (it is assumed that modelled schemes cover the full range of agricultural plastic applications). This results in the steep jump in collection rates seen following the implementation of new EPR schemes (and expansion in the scope of existing EPR schemes). Following this initial sharp increase, collection rates are modelled to increase steadily year-on-year until the scheme meets best-practice collection rate targets.

All policy measures result in a significant increase in collection rates relative to the baseline. In 2035, the increase in collection rates achieved through EPR schemes relative to the baseline ranges from 6.5% (for voluntary EPR schemes) to 29% (*mandatory EPR + participation requirement*). The voluntary EPR schemes with no incentive are modelled to achieve similar expected collection rates as incentivised schemes, however it is assumed that incentivised schemes will enable expected collection rates to be reached more quickly than non-incentivised schemes.

The distribution of changes in collection rate across the main categories of agricultural plastic applications are shown in Figure 8-2. This shows a comparison of rates for each policy measure in 2035 i.e. after the full impact of all policy measures has taken place.

Figure 8-2: Collection Rates (2035), %



This figure shows that the trajectory of collection rates for each these high-level categories follows a similar pattern as exists within current schemes, i.e. those agri-plastics for which collection rates are currently higher, continue to exhibit higher than average collection rates even as overall scheme performance increases. The exception to this is the *mandatory EPR + participation requirement* measure, for which the model outputs demonstrate that all plastic applications must reach very high collection rates to achieve an overall collection rate of 95%.

Modelled recycling rates over time are shown in Figure 8-3, and final recycling rates achieved in 2035 (after the full impact of all policy measures has taken place) are detailed in Table 8-2.

Figure 8-3: Modelled Recycling Rates (2019 to 2040), %

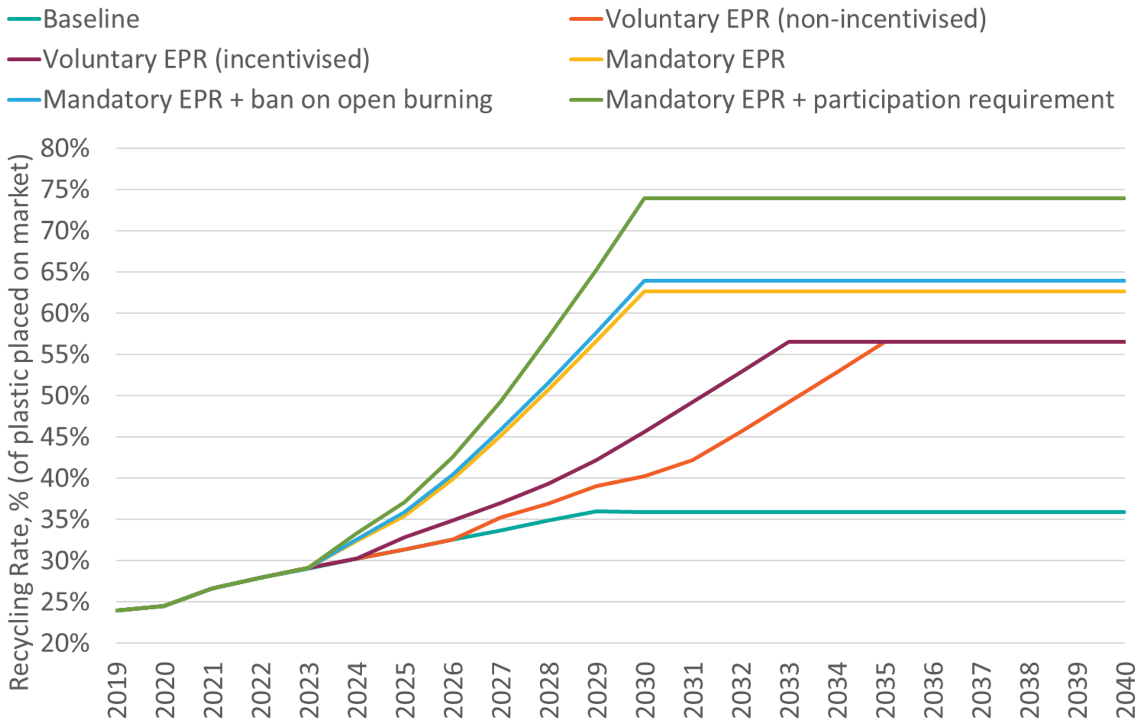


Table 8-2: Modelled Recycling Rates (2035), %

Measure	Plastic Recycling Rate, % of Plastic Placed on Market
Baseline	35.9%
Voluntary EPR (non-incentivised)	56.5%
Voluntary EPR (incentivised)	56.5%
Mandatory EPR	62.6%
Mandatory EPR + ban on open burning	63.9%
Mandatory EPR + participation requirement	73.9%

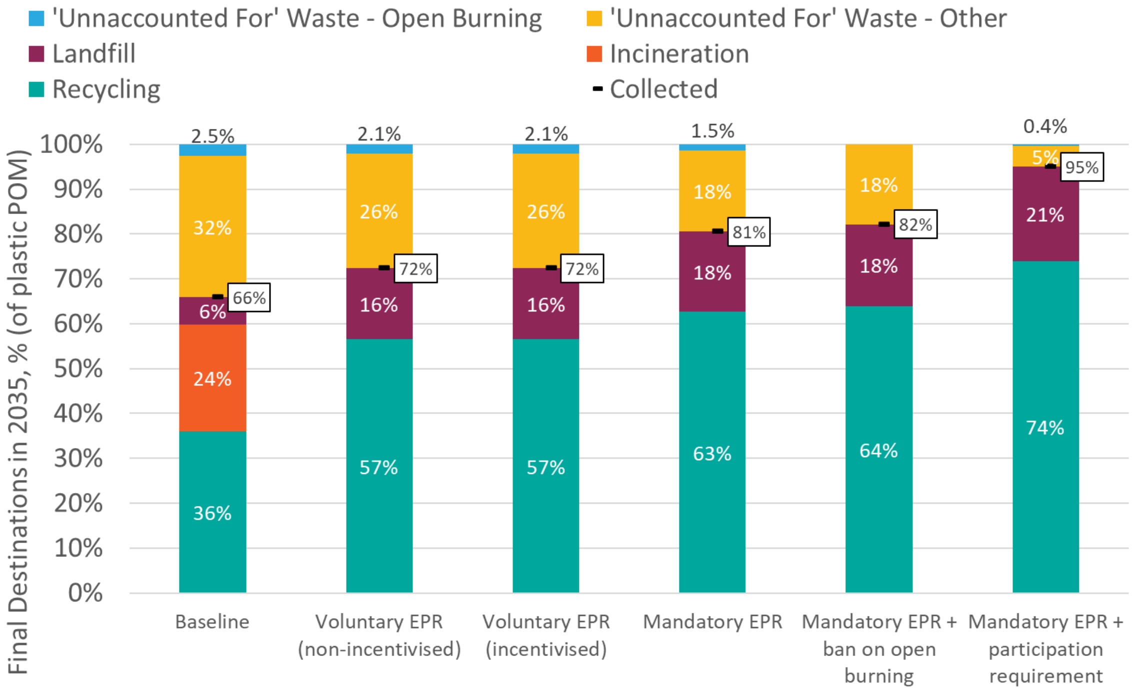
Similarly to collection rates, significant increases in recycling rates can be achieved through implementation of EPR schemes, with a progressively greater impact achievable from stronger (i.e. mandatory and/or with bans or participation requirements) policy measures.

The recycling rates presented here are final rates, that is, as would be measured at the output of plastic reprocessors. The increase in recycling rates shown results not only from the increase in collection rates (through implementation of EPR schemes), but also progressive improvements in the onward management of collected waste leading to reduced loss rates (and therefore a greater proportion of input-material is recycled) over time.

It should be noted that the slightly curved trajectories for recycling rates in Figure 8-3 are due to the methodology applied to adjusting collection rates for individual plastic applications. As collection rates are increased by an equal amount year on year for each application, the overall impact on collection rates (i.e. the average of these individual collection rates weighted by the quantity of waste generated for each application) is not constant year-on-year, although the variability in change in collection rate year-on-year is low.

Finally, we present the final destinations of plastic waste generated in 2035 (after the full impact of all policy measures has taken place) in Figure 8-4.

Figure 8-4: Final Destinations of Plastic Waste (2035), %



This figure shows the modelled impact of the requirement, under the Waste Framework Directive (as amended) "*to ensure that waste that has been separately collected…is not* *incinerated"*. As discussed in Appendix A.6.2.3., it is assumed that this requirement is progressively implemented by EPR schemes. The proportion of 'unaccounted for' waste is reduced as collection rates increase, with a proportionate reduction in waste that is burnt on-site. The *mandatory EPR + ban on open burning* scenario eliminates open burning completely (this leads to a significant increase in environmental benefit as discussed in Section 8.3).

8.2 Economic Impacts

Economic impacts are modelled for the two main stakeholder groups for this project: farmers and producers of agricultural plastic products. A complete description of the approach taken to modelling financial costs is provided in Appendix A.7.3 and summarised here. In broad terms, the modelling considers who pays the end-of-life costs, and at what point.

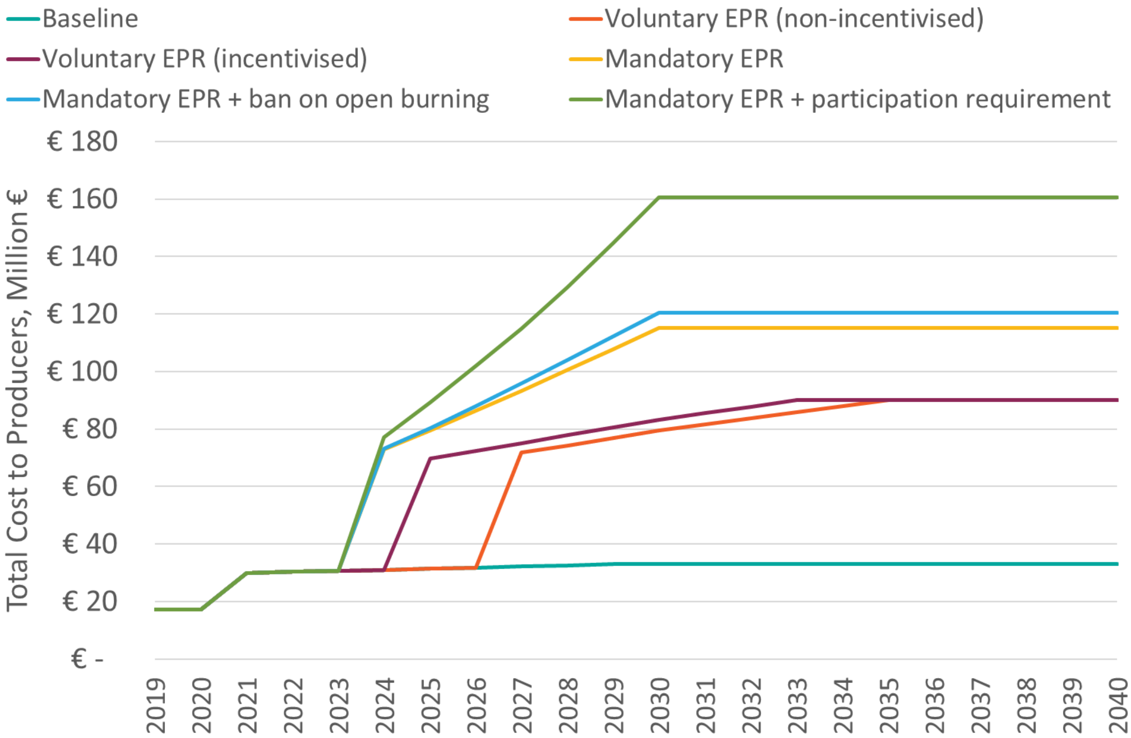
In terms of the cost of waste management, even if producers do pass on some or all of the EPR fees to farmers, this cost is now front-loaded i.e. it is included in the initial cost of plastic product rather than as end-of-life costs. Farmers are therefore more likely to properly dispose of waste if there is no additional cost at the end-of-life (or, if producer fees only partially cover the cost of waste management – as is commonly the case in existing schemes - a lower cost relative to the absence of an EPR scheme).

The estimated net costs of waste management are distributed in the model across producers (with some or all the costs being passed on to farmers at the point of purchase), and farmers directly incurring costs at the end-of-life. For the baseline, the average current costs in the EU are applied. For modelled EPR schemes, the proportion of end-of-life management costs paid by EPR fees (by producers) is adjusted in line with the observed relationship between EPR fees and collection rates – i.e. EPR fees increase as the collection rate increases. This occurs as a consequence of an increase in the tonnage of collected waste and therefore the quantity of waste for which producers are required to pay for the cost of collection and onward management.

It is assumed that under the highest performance option, the *mandatory EPR + participation requirement* measure, the full cost of waste management will be funded through EPR fees. EPR fees are then calculated for all time periods and scenarios based on the relative difference between the modelled collection rate and that achieved under the highest performance option. A similar (but inverse) methodology is applied for the calculation of costs to farmers, i.e. costs to farmers (i.e. costs paid directly at end of life) decrease as collection rates increase.

Total costs to producers over time for the baseline and each of the modelled measures are shown in Figure 8-5.

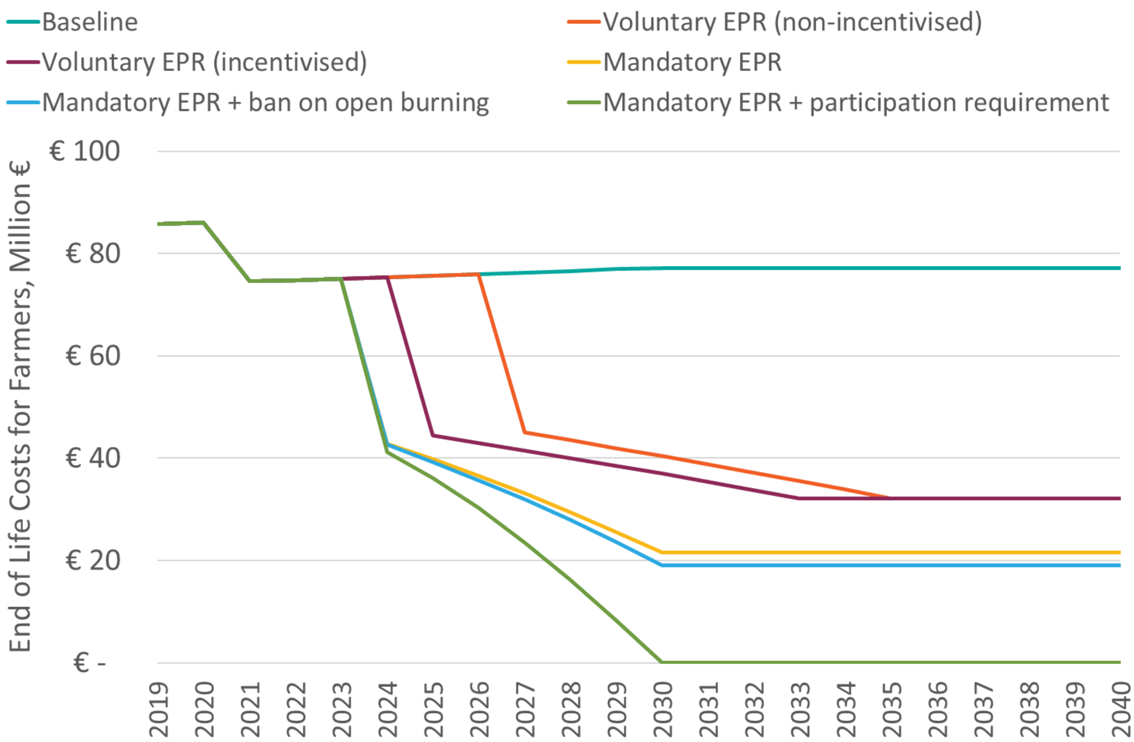
Figure 8-5: Total Cost to Producers (2019 to 2040), € Million



An initial sharp increase in costs is seen after the modelled implementation of each of the EPR schemes, this is due to the increase in the overall quantity of agricultural plastic in the EU within the scope of an EPR scheme. Costs then change by an approximately equal amount year on year as the proportion of end-of-life costs paid by producers increases with increasing collection rates. In 2035, the change in costs to producers (relative to the baseline) are modelled to range from an additional €57 million per annum (for voluntary EPR schemes) to €127 million per annum (for *mandatory EPR + participation requirement*). The total cost to producers ranges from approximately €90 million per annum to €160 million per annum, depending on the EPR scheme adopted. These figures represent from 5% to 9% of the estimated €1.8 billion in annual sales of agri-plastics in the EU (note this annual sales figure is based on internal analysis and is highly uncertain, but nevertheless provides a useful indicative comparison; see A.7.3 for more detail).

Projected costs paid directly by farmers for end-of-life management demonstrate similar but inverse trends over time, as shown in Figure 8-6. The impact of planned EPR schemes beginning in 2020 (for UK and Spain – Andalusia) are clearly shown in this diagram, as for producer fees (Figure 8-5). These result in a decrease in costs borne by farmers when the schemes are modelled to begin having an impact in the following year (2021). Costs for all schemes then follow a trajectory in line with modelled EPR scheme start dates and impact on collection rates over time. In 2035, the reduction in costs paid by farmers at end-of-life (relative to the baseline) range from €45 million per annum in cost savings (for voluntary EPR schemes) to €77 million per annum (for *mandatory EPR + participation requirement*).

Figure 8-6: End of Life Costs for Farmers, € Million

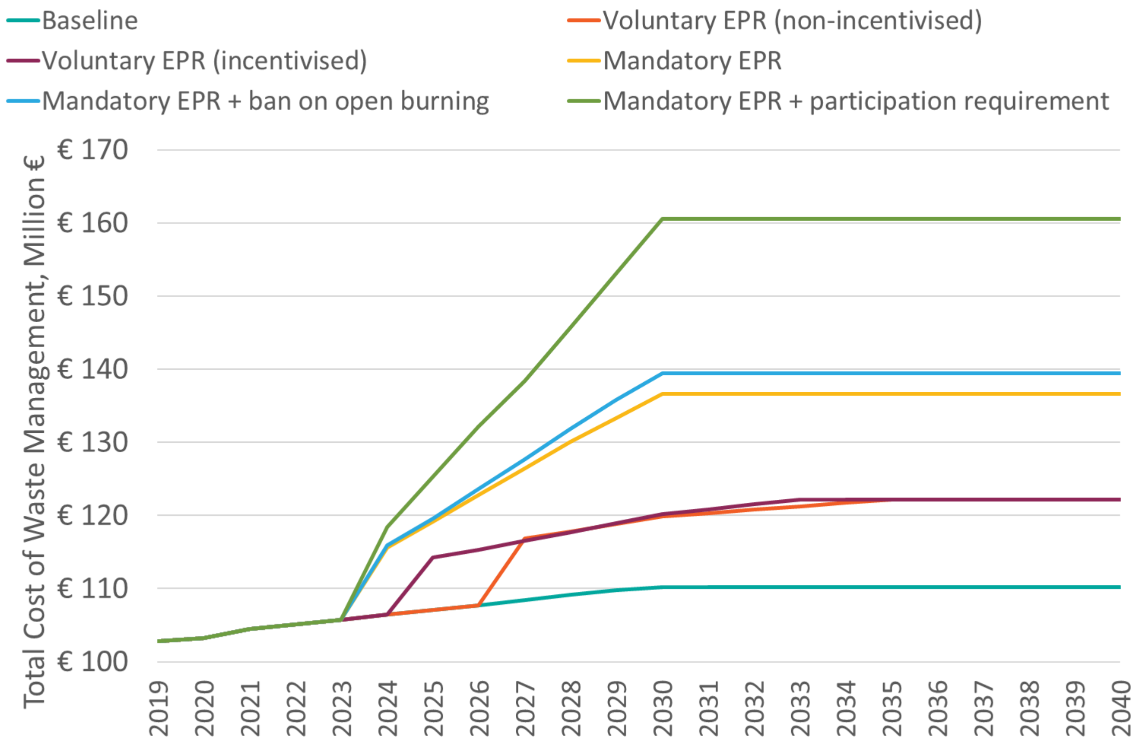


As discussed, the total cost per tonne of waste management for each application remains fixed and the cost model distributes this cost between producer fees and end-of-life costs for farmers. Waste that is not collected i.e. 'unaccounted for' waste, has no waste management cost associated with it – there is no cost for leaving waste in the environment or open burning/dumping. In practice, some of this waste may be collected via unreported local collection schemes and therefore have a collection cost, however, the extent of such collection is not reported in any known dataset and so no such cost is included in modelling

As the collection rate (and total number of tonnes of waste collected) increases in the scenarios, the costs of waste management also increase. This is because 'unaccounted for' waste, that previously had no financial cost associated with waste management (but significant environmental costs, see Section 8.3), is now properly collected and now has a management cost associated with it.

The net costs of waste management, i.e. the sum of producer fees and end-of life costs for farmers, are shown in Figure 8-7. As would be expected (given the net cost per tonne of waste management stays fixed in our model), the change in net costs follows the same pattern as the change in collection rate (Figure 8-1).

Figure 8-7: Net Costs of Waste Management, € Million



The ToR asked for a presentation of the cost per percent improvement in quantities recycled for the different options. While it is, in principle, possible to take the net increase in waste management costs for each option and divide these by the percentage increase in recycling achieved, this does not provide a meaningful comparison.

Firstly, the marginal cost of achieving an extra percentage point in recycling will vary based on the starting point. In order to meet a specific recycling target, it makes sense to start by collecting the agri-plastics that are cheapest and easiest to collect and recycle, gradually moving on to collect and recycle those that are increasingly challenging – for reasons such as geographical location, levels of contamination, low end value etc.

Accordingly, all else being equal, an increase in recycling from 20% to 21% should be achieved at a lower incremental cost than an increase from 40% to 41% (with a move from 60% to 61% presenting an even higher incremental cost).

However, the shape of this ‘cost curve’ will vary by scheme depending on factors (individually and in combination) such as:

- The geographical concentration in the use of agri-plastics (it’s cheaper to collect agri-plastics if the users are geographically concentrated);
- The intensity of use – if a small number of farms are using large amounts of agri-plastics this can be collected more efficiently than a large number of farms using small amounts;
- The types of agri-plastics being used; and

- The variety of different types of agriplastics being used.

Section 7.1.4 has already described some of the relative merits of mandatory schemes versus voluntary schemes, concluding that:

- Mandatory schemes are likely to be more stable than voluntary schemes at the very highest collection rates
- Under a mandatory scheme there is less need to manage the risk of free-riders, and thus full costs can more readily be incorporated into the price of agri-plastics, meaning farmers are not required to pay collection fees
- Mandatory schemes provide more confidence to investors in recycling facilities that there will be a continued supply of feedstock material in future years
- Mandatory schemes provide a more stable platform for the collection of comprehensive, and complete, data on the use and return of agri-plastics
- Mandatory schemes guarantee a level playing field for all producers

In terms of cost curves, depending on the way in which mandatory schemes are specified in terms of collection coverage requirements for example, and the timescale of rollout for collection coverage, voluntary schemes might be expected to be cheaper per tonne recycled at lower levels of collection. This would occur if the focus were on the cheapest to collect and most readily available agri-plastics, that also have a positive material value.

However, as also described in section 7.1.4, voluntary schemes are likely to become unstable at higher collection rates given that individual producers might decide to opt out as the marginal costs of the scheme (and thus fees) increase. This would place a higher cost burden on the smaller number of producers remaining in the scheme, which could then spur further departures, and so on.

In addition, under mandatory schemes, the higher likelihood of achieving better quality data that can help with planning logistics, especially where combined with requirements to participate could actually mean that a given level of collection and recycling (even at relatively low or moderate recycling rates) could be achieved more efficiently than under a voluntary scheme.

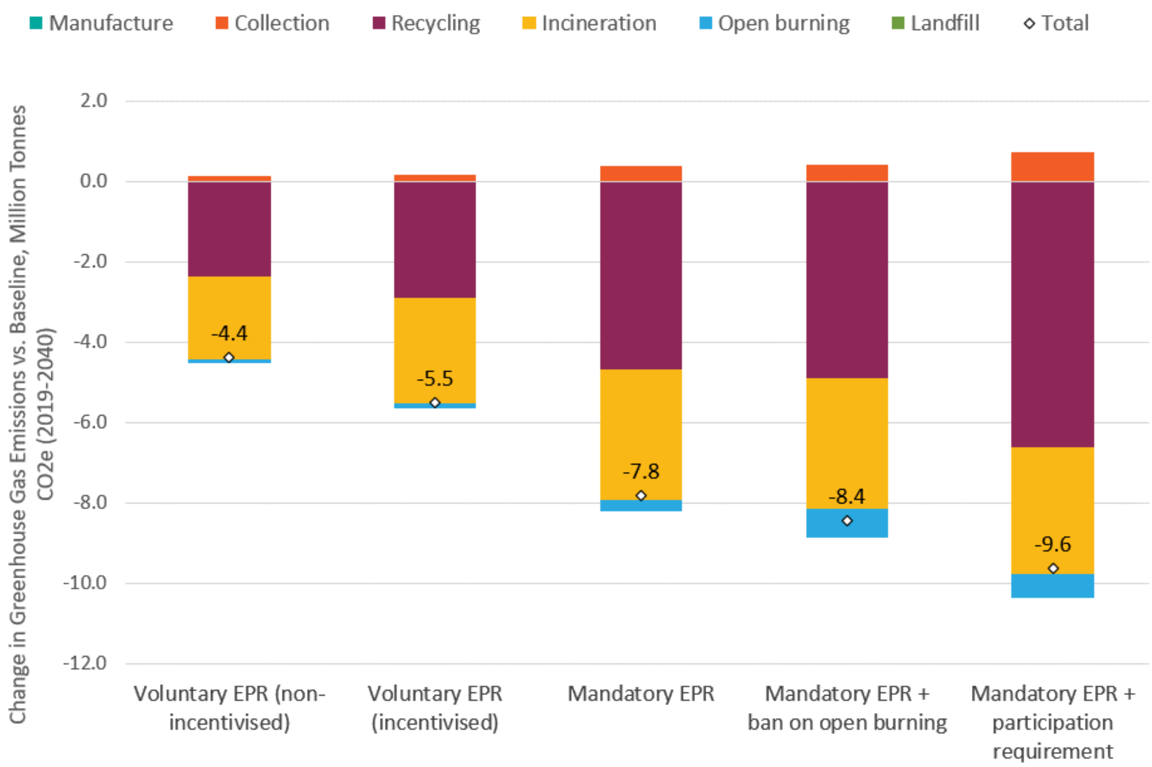
The absence of data means that this discussion is, of necessity, theoretical in nature. However, working through the different design considerations, it is clear that mandatory schemes give far greater certainty that higher levels of recycling can be achieved, and in enabling higher levels of collection and recycling, can ensure that the costs of managing plastics at end of life are adequately covered by producers, rather than being placed directly on farmers.

8.3 Environmental Impacts

Environmental impacts are presented both in terms of net greenhouse gas emissions, and in terms of monetised externalities, including the external costs of climate change, air quality impacts and estimates of the costs related to the disamenity of waste littered and/or left in the environment.

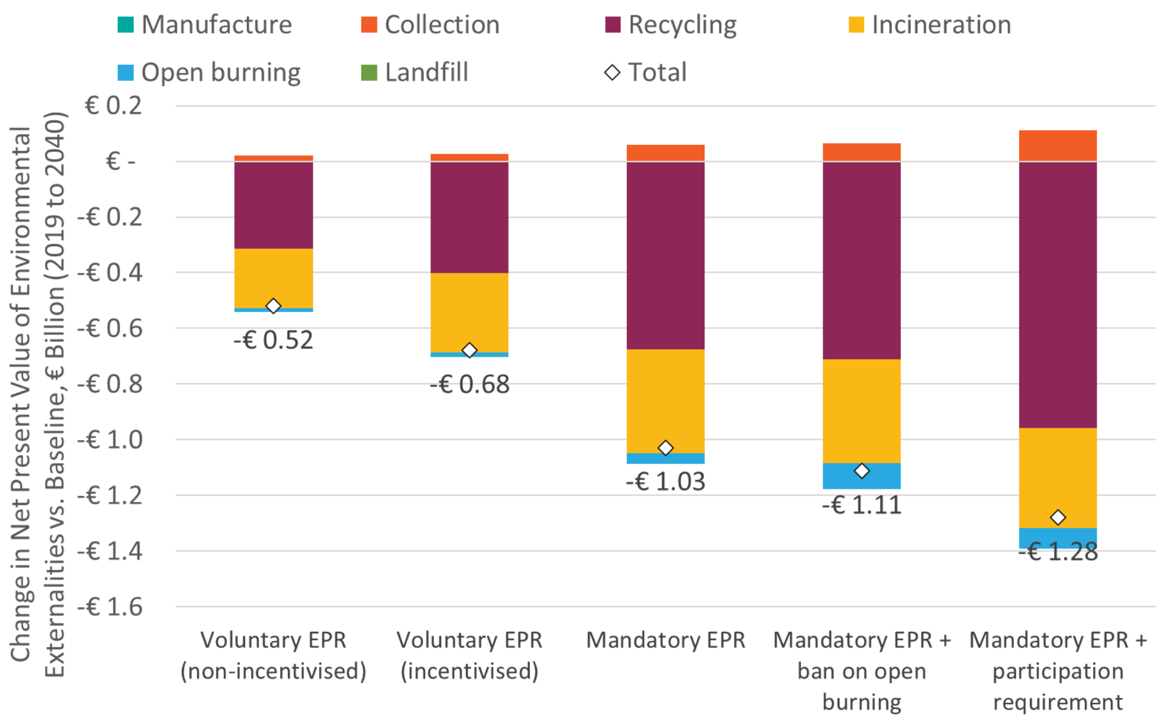
The total change in greenhouse gas emissions (relative to the baseline) for the modelled measures is shown in Figure 8-8. This figure shows the sum of all impacts over the modelled time period i.e. 2019 to 2040. The total carbon savings range from 4.4 million tonnes CO_2 equivalent (for voluntary schemes) to 9.6 million tonnes CO_2 equivalent (for *mandatory EPR + participation requirement*). The majority of this saving is due to the carbon benefits of increased recycling, whilst significant savings are also achieved through decreased incineration and open burning. These carbon benefits significantly outweigh the additional carbon produced through increased waste collections (i.e. the additional collections to obtain the agri-plastics that would otherwise have been burnt or buried on site).

Figure 8-8: Total Change in Greenhouse Gas Emissions (2019 to 2040), Million Tonnes CO2e



The change in environmental externalities for each of the measures modelled is presented in Figure 8-9. These are presented in terms of the change in Net Present Value (NPV) of externalities modelled for 2019 to 2040, based on a 4% social discount rate. Environmental benefits of up to €1.3 billion NPV relative to the baseline (for *mandatory EPR + participation requirement*) are modelled, with typical mandatory schemes achieving benefits closer to €1 billion NPC and voluntary schemes around €0.5-0.7 billion NPV.

Figure 8-9: Total Change in Net Present Value of Environmental Externalities (2019 to 2040), € Billion



Most of the environmental externalities demonstrate a similar trend as observed for greenhouse gas emissions i.e. significant savings in externalities from increased recycling, and, to a lesser degree from reduced incineration and open burning. Savings from open burning, whilst smaller than incineration, are greater in terms of the per-tonne saving achieved as open burning has a significantly greater environmental disbenefit associated with it. The unit impacts for open burning include estimates of the additional impact of black carbon emissions on climate change and air quality.

Further savings will be achieved through the reduction in agricultural plastics left in the environment. It is evident that this mismanaged waste has a disamenity impact – i.e. that the presence of mismanaged waste in the wider environment negatively affects people's enjoyment of that environment.[273] However, the *magnitude* of that disamenity is uncertain, and has been estimated in only a small number of previous studies, commonly based on willingness to pay (WTP) approaches.

There are, however, no studies to date estimating the visual disamenity of *agricultural plastics* in the environment (i.e. a monetary proxy of the extent to which people are

---

[273] For example this is an issue highlighted by some NGOs as a concern in terms of pollution of rivers (see https://www.wyeuskfoundation.org/blogs/e-news/plastics-in-rivers-and-seas) and also of ingestion of commercial greenhouse sheeting by whales (https://www.theguardian.com/world/2013/mar/08/spain-sperm-whale-death-swallowed-plastic)

upset by seeing agri-plastics in the environment) or indeed the upset of knowing that such plastics enter the environment, including soil, watercourses and the marine environment. There is less public concern expressed about agri-plastics in the environment than for items such as plastic bottles, food containers, straws and stirrers, and agri-plastics are not part of the general population's daily experience, as is the case for litter in our towns and on beaches. However, there is a visual impact, especially where plastics are seen trapped in hedgerows, and in riverside trees after floods, as well as the as yet unquantified impacts on soil health and that of freshwater and marine environments.

In the absence of any estimates of the unit disamenity, it was not possible to include these costs in the environmental externalities presented in Figure 8-9. However, it is clear that these costs are not zero. In order to provide an indicative and very much speculative figure, unit (i.e. per tonne) disamenity costs from a recent impact assessment on single use plastics conducted by ICF and Eunomia for the European Commission were scaled down by a factor of 10.[274] This means that the disamenity impacts of one tonne of agri-plastics in the environment are set at one-tenth (i.e. 10%) of that for a tonne of single-use plastics such as plastic bottles, food packaging etc. The logic for this assumption is that the impacts are likely to be a lot less than for these single-use plastic types, which are littered in much more visible and populous locations. It is recognised that this is an arbitrary figure, and further research would need to be undertaken to provide greater certainty around the magnitude of the disamenity if such a figure were to be used in a future impact assessment.

Using this disamenity, and assuming that a similar quantity of agricultural plastic waste is left in the environment as is currently sent to open burning, a total disamenity of €182 million is calculated. As discussed, this is a speculative assessment not based on actual data. However, we suggest it characterises the order of magnitude of the potential environmental benefit (i.e. the 'avoided' disamenity) that could be achieved by reducing the amount of waste left in the environment. A value of €182 million is significant, particularly considering this is the environmental benefit accrued in only a single year, not in net present value terms over the model period (as shown in Figure 8-9).

Uncollected agri-plastics that subsequently fragment over time could also mean that microplastic particles accumulate in agricultural soil, and potentially enter watercourses. Section 3.4 summarises the state of knowledge on the impacts of agricultural plastic residues (microplastics) on soil health and agricultural yields. However, there is not enough information available to be able to derive a quantitative estimate of such microplastics stocks and flows, and the way in which they might be affected as collection rates increase. Suffice to say that the higher the collection rate, the lower the amount of potentially micro-plastic forming agri-plastic that remains in the environment each year.

[274] ICF and Eunomia (2018) Assessment of measures to reduce marine litter from single use plastics, Report for DG Environment, https://ec.europa.eu/environment/waste/pdf/Study_sups.pdf

9.0 Comparison of Policy Options

A requirement for the separate collection of plastic waste where it is technically, environmentally and economically practicable and appropriate already exists under Article 11 (1) of the WFD (with a deadline for implementation of 2015). This requirement extends to agricultural plastic waste.

However, APE Europe has estimated that only ~38% of agri-plastic non-packaging waste generated in the EU was separately collected in 2019. Furthermore, despite agri-plastics having a high potential for recycling, it is estimated that only 28% of the non-packaging agri-plastic waste collected in the EU is currently recycled (while an estimated 42% is landfilled and 30% sent to energy recovery).

The problem drivers behind such low collection and recycling rates for conventional agri-plastics were investigated. Essentially, there is a lack of demand from recyclers for most agri-plastic waste due to its high contamination rates and limited end markets (a problem exacerbated in recent years by an influx of high quality plastic feedstock onto the European market after China stopped accepting it). This feeds into a lack of incentives for the separate collection of agri-plastics, if left up to the free market. Furthermore, where separate collection schemes for agri-plastics do exist, there may not always be sufficient incentives for all farmers to participate, especially if they can manage the agri-plastic waste more cheaply or more conveniently in another way – e.g. burning on site or drip feeding into a mixed waste collection stream.

A number of policy objectives for improving the management of agri-plastics at EOL were formulated (based closely on the problem drivers). The general objectives are as follows:

- To reduce the leakage of agricultural plastics into the environment;
- To ensure the use and EOL management of agricultural plastics adheres to the waste hierarchy; and
- For the polluter pays principle to be respected in the case of EOL management of agricultural plastics

A number of specific policy objectives were also generated (see Section 6.2.2). Based on these specific objectives, a selection of policy measures were developed and evaluated (see Table 6-3). These centred largely around EPR, as EPR has the potential to achieve a number of the general and specific policy objectives formulated as part of this project:

- Ensure sufficient incentives for the operation of comprehensive collection schemes for used agricultural plastics at end of life
- Ensure widespread understanding and awareness among farmers as to the agricultural plastic collection schemes available and the benefits of participating
- Ensure sufficient incentives for farmers to remove as much contamination from agricultural plastic waste before collection

- Ensure sufficient incentives for agricultural plastic producers to include recyclate in the manufacture of new products (potentially through fee modulation)

EPR Policy Measures

EPR was deemed more proportionate and targeted than other longlisted policy options (e.g. a tax on virgin plastic production). Also, EPR will help member states achieve the requirement for the separate collection of plastic waste, as set out in the WFD.

There are a number of ways in which EPR can be implemented and three options have been compared in this study: voluntary (incentivised); voluntary (non-incentivised); and mandatory. Further to this, the mandatory EPR option has been modelled in combination with two additional policy measures (separately) which enhance its effect: a ban on open burning plus enforcement, and a requirement placed on farmers to participate in an agri-plastics collection scheme.

Qualitative analysis suggests that mandatory EPR has a number of benefits over voluntary EPR, these are summarised below and also in Table 9-1:

- Mandatory schemes are likely to be more stable than voluntary schemes at the very highest collection rates;
- Under a mandatory scheme there is less need to manage the risk of free-riders, for example by sharing costs between the producer levy and farmer collection fees. This is important because fees at the point of collection may act as a disincentive for farmers to return agri-plastics;
- Mandatory schemes provide more confidence to investors in recycling facilities that there will be a continued supply of feedstock material in future years;
- Mandatory schemes provide a more stable platform for the collection of comprehensive data on the use and return of agri-plastics;
- Mandatory schemes guarantee a level playing field for all producers; and,
- Mandatory schemes can be more effectively combined with other measures which enhance the performance of the collection scheme (this is because a mandatory system is inherently more stable at high collection rates and also because it is easier to implement more comprehensive and detailed data collection requirements under a mandatory scheme).

The modelled performance of the different EPR options indicates that mandatory EPR is likely to achieve higher collection and recycling rates across the EU than voluntary EPR, though all EPR options result in a significant increase in collection and recycling rates versus the baseline (see Table 9-1). Note that the collection and recycling rates presented in Table 9-1 are snapshots in time; by 2040, both the incentivised and non-incentivised voluntary EPR options have achieved the same performance. It takes non-incentivised voluntary EPR longer to achieve that performance level as it is assumed to be more difficult to get very high levels of producer participation. Therefore, the overall cost is lower to producers for the non-incentivised option compared to the incentivised option. Similarly, the reduction in GHG emissions is slightly lower for the non-incentivised option compared to the incentivised option.

Table 9-1: Comparison of EPR Policy Measures

	Stability at high collection rates	Confidence to investors in recycling facilities	Comprehensive data collection	Level playing field / fairness for producers	Collection Rate (incl. contamination) (2040)	Recycling Rate (2040), % of agri-plastic placed on market	Change in GHG Emissions (2019-2035), Million Tonnes CO_2e	Change in NPV of Environmental Externalities (2019 to 2040), € Billion[1]	Change in NPV of Net Costs of Waste Management (2019 to 2040), € Billion
Baseline	N/A	N/A	N/A	N/A	**66%**	**36%**	-	-	-
Voluntary EPR (non-incentivised)	Potentially unstable	Medium	More challenging to agree and enforce	Risk of free-riders	**72%**	**57%**	**-4.4**	**-€ 0.52**	**€ 0.08**
Voluntary EPR (incentivised)	Potentially unstable	Medium	More challenging to agree and enforce	Risk of free-riders	**72%**	**57%**	**-5.5**	**-€ 0.68**	**€ 0.09**
Mandatory EPR	Stable	High	Can be required by the scheme	High	**81%**	**63%**	**-7.8**	**-€ 1.03**	**€ 0.22**
Mandatory EPR + ban on open burning	Stable	High	Can be required by the scheme	High	**82%**	**64%**	**-8.4**	**-€ 1.11**	**€ 0.24**
Mandatory EPR + participation requirement	Stable	High	Can be required by the scheme	High	**95%**	**74%**	**-9.6**	**-€ 1.28**	**€ 0.40**

1) Net present value (NPV) represents the discounted flow of costs and benefits

2) Note that the marginal cost to achieve a percentage point increase in the collection rate increases as the collection rate gets higher. For example, the marginal cost of a collection rate increase from 50% to 55% will be less than the marginal cost of a collection rate increase from 75% to 80%. The cost per percentage point improvement presented in the table is therefore an average over the entire increase in collection and recycling rates 2019-2040.

The net cost of waste management increases compared to the baseline for all options due to a reduction in the volume of 'unaccounted for' waste, which has no waste management cost associated with it (but is associated with significant environmental costs). Also, under EPR, the cost of waste management is transferred from being incurred directly by farmers at a product's EOL, to being incurred by producers when they place product on the market (even if this cost is passed onto farmers, it is front-loaded and included in the cost of the plastic product). It is assumed that farmers are more likely to properly dispose of waste if there is no additional cost of doing so at EOL.

The environmental benefits associated with the various EPR options are closely linked to the collection and recycling rates achieved (e.g. the majority of carbon savings are due to carbon benefits of increased recycling, though significant savings are also achieved through decreased incineration and decreased open burning). As a result, mandatory EPR is modelled as achieving greater environmental benefits than voluntary EPR. Though again, all EPR options represent significant environmental benefits compared to the baseline.

Our study concludes that the implementation of EPR for agri-plastics is likely to lead to significant improvements in the collection and recycling rate for agri-plastics across the EU. As a policy measure it is proportionate and targeted. It will also enable member states to achieve the separate collection requirement for plastic waste, as set out in the WFD, and for which the 2015 deadline has already passed. Those EPR options at the stronger end of the spectrum (i.e. mandatory EPR) are likely to be most effective, though there are examples of successful voluntary agri-plastic EPR schemes (e.g. ADIVALOR in France).

Given the existing requirement for separate collection of plastic waste under Article 11 (1) of the WFD, it is recommended that the European Commission develops guidance that encourages Member States to implement EPR in order to meet their obligations under the WFD in respect of agricultural plastic waste. It is further recommended that such guidance considers the relative merits of voluntary versus mandatory approaches, and best practice in respect of the establishment and operation of EPR schemes, building on the findings of the current study.

Biodegradable Agri-plastic Policy Measures

It is recommended that BDAPs are incorporated into agri-plastic EPR schemes. The EPR scheme can be used as a mechanism to collect data on how and where BDAPs are used (such data is useful to monitor the appropriate use of BDAPs). It is envisioned that BDAP producers would be exempt from contributing to EPR collection and treatment costs (as these do not apply to BDAPs), and instead required only to pay a data management admin fee.

Standards for BDAPs

Where a standard for BDAP exists (e.g. EN 17033 for mulch films), only certified BDAPs would be exempt from the EPR collection and treatment costs. This measure therefore supports the appropriate use of BDAPs by providing a framework for producers to verify claims. For the integration of BDAPs into EPR schemes to be effective, the EPR scheme in question would need to have full producer participation and strong data collection requirements – most easily achievable under a mandatory approach.

If the current EN 17033 is to be referenced in EPR schemes as evidence of conformance and exemption from EPR disposal costs it should be revised to reflect best practice and uncertainty. Currently the Standard suggest that growers incorporate the material into soil after the growing period. This may not be possible (or typical practice) for some crops (e.g. vineyards) and therefore this practice is not always observed. It is recommended that no exemption is given to any crop type where the grower cannot provide evidence that soil incorporation is taking place.

For mulch films and other BDAPs that remain on the soil surface a new Standard and associated test method will have to be developed in order to provide a framework to allow such products to benefit from EPR exemptions. Furthermore, BDAP products that do not have a verified and accepted Standard associated with them should be considered as 'mismanaged' if left in the environment in the same way as conventional plastics are currently.

Minimum Thickness / Tensile Strength for Conventional Mulch Films

A final policy measure considered is a mandatory minimum thickness / tensile strength for conventional mulch films, to minimise the risk of tearing during the removal process (and plastic fragments accumulating in the environment). Currently, there is very limited quantitative evidence available to link specific mulch film thicknesses to the proportion of plastic remaining in the environment post-removal. It is therefore recommended that further research is conducted to better understand this relationship before any mandatory minimum thickness (or strength) is recommended (see 7.4 for more detail).

The European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) may be used as vehicle for providing verification for a minimum standard.

10.0 Further Research Requirements and Associated Recommendations

Throughout this study there has been a notable lack of verifiable data from which to draw conclusions. The following research Requirements (typically associated with filling in data gaps) and associated recommendations are highlighted:

Throughout this study there has been a notable lack of verifiable data from which to draw conclusions. Therefore, the following data gaps and further research requirements are highlighted:

Data Gaps

- Statistical data on the volumes of agri-plastics placed on the market, their uses and their end-of-life fate at Member State level are missing.
- Much of the research and published evidence on biodegradable mulch films is based on the experience from Southern Europe, in particular Italy. Published data for Northern Europe is absent and the accumulation model developed for this study was based upon observations from one US study.
- The migration of plastic residues into other environments (e.g. waterways) from either conventional or biodegradable mulches incorporated into soil has not been studied or quantified to date.
- There is no verifiable data around the typical amount of conventional mulch film that remains on the field after collection. Whilst several figures have been quoted by stakeholders (ranging from 60-100% removal), this is not confirmed with empirical evidence.
- There is no verifiable data (only expert opinion) around the link between mulch film thickness and the typical amount of conventional mulch film that remains on the field after collection.
- There is no research on the magnitude of the disamenity impact associated with agri-plastics left in the environment.

Cross Cutting Recommendations for Further Research

- Build a robust and accurate monitoring data system on plastic for agriculture. Data collection under EPR could provide this data, and coverage will be best if the EPR schemes are mandatory.
- Develop a spatial model of potential flows from agricultural land to waterways that takes into account the location of farms in relationship to waterways, soil erosion and rain events**.**

Recommendations for Further Research on Conventional Agri-Plastics

- Commission a field-based study focused on determining typical and optimal practice for conventional mulch film removal. Variables such as crop type and material thickness and removal equipment should be considered.

- Determine whether the existing requirements in the European Standard for "Thermoplastic mulch films recoverable after use, for use in agriculture and horticulture" (EN 13655) are sufficient that, if made mandatory, will lead to greater removal from soil of conventional mulch films.
- Develop further policy options to enforce/encourage good practice once a dataset for both typical and optimal practice for conventional mulch film removal is acquired. These could *inter alia* include:
    - Requirements for particular removal equipment
    - Guidance for best practice
    - Mulch film design requirements e.g. minimum thickness
    - Restriction of conventional mulch films for particular applications (e.g. for crop types where evidence shows that complete removal of conventional mulch films is not possible)
- Assess how effective mechanical mulch film removal techniques (e.g. the RAFU technology trialled in France) are at reducing contamination, and whether any policies supporting the use of this technology should be implemented.

Recommendations for Further Research on Biodegradable Agri-Plastics

- Conduct further studies into the use of biodegradable mulch films that sample soil over several growing seasons in different climates. Any findings from this research may need to be reflected in an update to EN 17033.
- Develop a standard test method for biodegradation and associated limit threshold requirements for specific products that are left *on* the soil (rather than the existing tests for *in* the soil) e.g. for tree protection products.
- Alongside identifying where particular conventional mulch film applications may prevent removal from the soil, these applications may benefit from incentives for the use of biodegradable mulch films.

APPENDICES

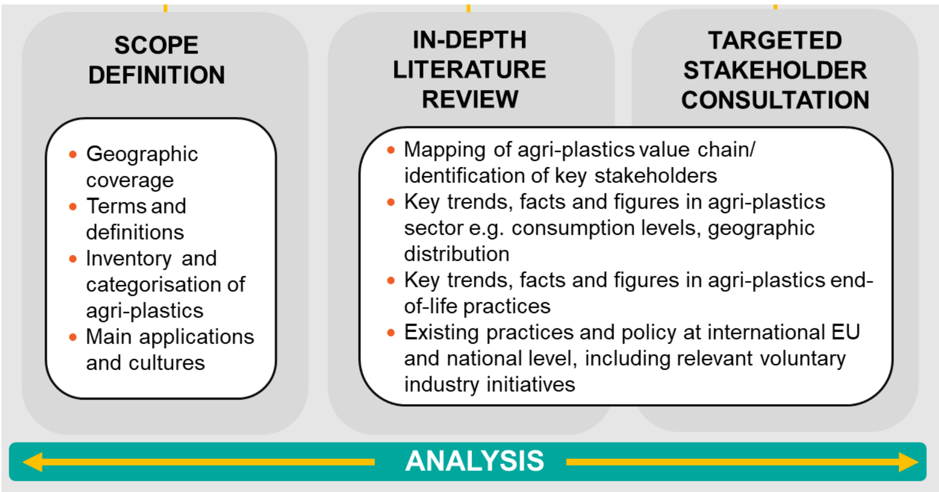
A.1.0 Data Collection Methodology

Figure A1. 1 illustrates the overall approach for understanding the 'state of play' of agricultural plastics. The methodology applied consists of the following six steps:

- Step 1 – Selection of representative sample of MS
- Step 2 – Inventory and categorisation of agri-plastics
- Step 3 – Agri-plastics sector at EU and national level
- Step 4 – Agri-plastics waste management at EU and national level
- Step 5 – International policies and best practices
- Step 6 – Presentation of key findings

Key findings and data collected from the state of play fed the analysis of end-of-life practices for conventional plastics, biodegradable plastics as well as for the development of the baseline scenario(s).

Figure A1. 1: Approach for state of play



A.1.1 Data collection

A summary of the data collection process – carried out through **desk research and stakeholder consultation** is further detailed in the following subsections.

A.1.1.1 Desktop research and literature review

A large amount of literature was collected and reviewed, which included relevant documentation published by public authorities e.g. Ministries of Environment and Agriculture, EU institutions and industry as well as research and academic publications. A detailed list of sources can be found in the following section.

A.1.1.2 Targeted stakeholder consultation

Targeted stakeholder consultation has also been carried out in parallel to the data collected through literature in order to address any potential inconsistencies, uncertainties and data gaps. The objective of the stakeholder consultation is to gather key input for the state of play, notably in relation to challenges for increased collection, re-use and recycling, associated drivers and the main opportunities and barriers.

In addition to ensuring that relevant stakeholder input contributes to the data collected and analysed, efforts were also made to ensure that the feedback reflected as far as possible a representative overview of all the different stakeholder concerns and interests. As such, a wide range of stakeholders were approached, particularly industry actors from producers to recyclers as well as public authorities in charge of waste management, including collection, recycling and re-use operations. A summary of the stakeholder consultation is provided in Table A1. 1.

In particular, the project team has also worked in close collaboration with the Circular Plastics Alliance (CPA) in order to obtain necessary data on agri-plastics at both national and EU level, as well as to validate assumptions for estimations and key findings. The CPA was launched in December 2018 with the aim of promoting voluntary actions and commitments to achieve the objective of 10 million tonnes of recycled plastics used in products in Europe by 2025. The CPA gathers key public and private stakeholders in the plastics value chain, with access to important data on end-of-life practices, such as collection and sorting of agri-plastic waste and recycling, as well as associated challenges.

The following methods for stakeholder consultation have been used:

- **Questionnaires**: specifically adapted to the different stakeholder groups concerned e.g., plastic producers, recyclers, MS authorities, trade associations, etc.
- **Interviews** via telephone: with the aim of obtaining additional clarifications and feedback
- **Focus Groups:** Three online focus groups were held with a small number of participants to focus discussions on specific topics.
    - EPR for agricultural plastics
    - Spanish growers and producers of biodegradable agri-plastics
    - Italian growers and producers of biodegradable agri-plastics
- **Webinars:** Several dedicated webinars were organised on specific topics reaching a wider audience.
    - Webinars to introduce project and share early findings
    - Policy Options Webinar: Conventional plastics
    - Policy Options Webinar: Biodegradable plastics In particular, the project team has also worked in close collaboration with the Circular Plastics Alliance (CPA) in order to obtain necessary data on agri-plastics at both national and EU level, as well as to validate assumptions for estimations and key findings. The CPA was launched in December 2018 with the aim of promoting voluntary actions and commitments to achieve the objective

of 10 million tonnes of recycled plastics used in products in Europe by 2025. The CPA gathers key public and private stakeholders in the plastics value chain, with access to important data on end-of-life practices, such as collection and sorting of agri-plastic waste and recycling, as well as associated challenges.

This range of consultation approaches allowed the project to source data from a wide range of stakeholders and went beyond what was available through a standard literature review, by including policy statements and briefing documents.

Stakeholders had opportunities to raise questions on the project. Concerns in in the first webinar were raised around defining the product scope, geographical coverage and accuracy of data and analysis. Stakeholder inputs in this phase led to a re-evaluation of the risk associated with biodegradable agri-plastics as the initial analysis had relied on academic literature only. In the final webinar on biodegradable plastics clarity was gained on the use of terminology including ‘risk, mineralisation, and agronomic benefits, and there was widespread agreement with the need to regulate the usage of Biodegradable Mulch Films across Europe.

Table A1. 1: Status of Stakeholder Consultation

Organisations contacted	Scope	STATUS			
		Contacted, no response	Questionnaire	Webinar	Interview
ACR+ (Association of Cities and Region for sustainable Resource management)	EU	X			
Agricultural University of Athens	EU			X	X
APE Europe	EU		X	X	X
Barbier Group	EU				
BASF	EU		X	X	
CEDO	EU				X
CEJA (Young Farmer's association)	EU	X			
EPRO (European Association of Plastics Recycling and Recovery Organisations)	EU	X			
EUPC (European Plastics Converters)	EU	X			
European Bioplastics Association	EU		X	X	X
FEAD (European Federation Waste Management and Environmental Services)	EU		X	X	
IFSA (International Farming Systems Association)	EU	X			
International Association on Work in Agriculture	EU	X			
Plastics Recyclers Europe (PRE)	EU		X	X	
PlasticsEurope	EU			X	
Plastic Energy	EU				X
TAMA Europe	EU			X	X
Bulgarian Ministry of Agriculture	BU	X			
Bulgarian Ministry of Environment	BU	X			
Blitc EOOD	BU	X			
Elplast EOOD	BU	X			
ASAJA (Asociación Agraria de Jóvenes Agricultores)	ES			X	
ASOBIOCOM (Asociación Espanola de Plasticos Biodegradables Compostables)	ES			X	
Cooperativas Agroalimentarias Navarra	ES			X	

Organisations contacted	Scope	STATUS			
		Contacted, no response	Questionnaire	Webinar	Interview
Cooperativa Santiago Apóstol	ES			X	
Cooperativa SUCA (Andalucia)	ES			X	
FECOAM (Federación de Cooperativas Agrarias de Murcia)	ES			X	
Department of horticulture. Lleida University	ES			X	
Finnish Environment Institute (SYKE)	FI	X			
Finnish Ministry of Environment	FI	X			
Finnish Ministry of Agriculture	FI	X			
Finnish Plastics Recycling Ltd	FI	X			
YTT	FI	X			
University of Turku – Brahea Centre	FI		X	X	
MTK Farmers association	FI	X			
Smart and Lean Solutions Finland	FI	X			X
Finnish Plastics Industries Federation	FI	X			
French Ministry of Agriculture	FR	X			
A.D.I.VALOR	FR		X	X	X
ADEME	FR	X			
Irish Farm Films Producer Group (IFFPG)	IE			X	X
Azienda agricola F.lli. Tramonti S.S.	IT			X	
Azienda agricola Santoro Guido	IT			X	
Cooperativa SOLE di Parete(CE)	IT			X	
Novamont	IT			X	X
Ortofruititalia	IT			X	
Societá Agricola gli orti di Astolfi	IT			X	
German Federal Ministry of Environment	DE		X		
ERDE (Crop Plastics Recycling Germany)	DE	X			
Industrievereinigung Kunststoffverpackungen	DE	X			

Organisations contacted	Scope	STATUS			
		Contacted, no response	Questionnaire	Webinar	Interview
German Ministry of Agriculture	DE	X			
RIGK	DE			X	X
Netherlands Ministry of Water management	NL	X			
Daly Plastics Netherlands	NL	X			
Norweigan University of Science and Technology	NO		X		
Polish Ministry of Environment	PO	X			
Polish Ministry of Climate	PO	X			
Polish Ministry of Agriculture	PO	X			
Polish National Fund for Environmental Protection	PO	X			
Plast-Fol Sp.	PO	X			
Polish Association of Plastic Converters	PO	X			
Swedish Environmental Protection Agency	SE		X		X
Swedish Board of Agriculture (Jordbruks Verket)	SE	X			
SvenskRetur	SE		X		
Kretslopp et Recycling i Sverige AB	SE		X		
APE UK	UK			X	X
Berry BPI	UK				X
Staffordshire University Forensic Science Department	UK				X

A.2.0 Supporting Technical Information – Market Assessment

A.2.1 Additional information for EU level analysis

The following tables provide information about the agricultural plastic market in Europe including sales volumes and applications of agri-plastics.

Table A2.1: Main polymers and additives used in agri-plastic applications[275,276]

Applications	Conventional plastics	Biodegradable plastics	Additives
Greenhouse and large tunnel films	LDPE, LDPE.IR, EVA, LLDPE,	-	Anti-fog, photo-selective, UV stabilizers, long infra-red properties enhancer master-batch
Low tunnel films	LDPE, EVA, LLDPE, PVC	Starch , PCL, PBAT, PHA, PLA, PBS, TPS, cellulose	UV stabilizers, infra-red properties enhancer
Nursery films	LDPE, LLDPE	-	-
Direct covering (nonwoven /Floating covers)	PP, perforated LDPE	-	-

[275] Demetres B. et al (2013). Review, mapping and analysis of the agricultural plastic waste generation and consolidation in Europe.
[276] Scarascia, G. et al. (2012) "Plastic materials in European agriculture: Actual use and perspectives" Journal of Agricultural Engineering, Vol. 42, No.3

Applications	Conventional plastics	Biodegradable plastics	Additives
Covering vineyards and orchards	LDPE, EVA	-	UV stabilizers, coloured pigments
Mulching films	Transparent or black LDPE	Starch , PCL, PBAT, PHA, PLA, PBS, TPS, cellulose	Coloured pigments, UV stabilizers, carbon black
Woven nets (hail, windbreaks, bird, shading)	HDPE	-	Coloured pigments
Non-woven nets for collecting	PP, HDPE	-	Coloured pigments
Piping, irrigation /drainage	LDPE, HDPE, PVC, PRFV	-	Coloured pigments
Packaging (pesticide cans and fertiliser bags)	LDPE, HDPE	-	Coloured pigments
Products for harvesting and crop storage (containers, tanks, crates)	PVC, HDPE, PS, PP, GRP	-	-
Silage films and protective covering	LDPE	-	Coloured pigments
Other (rigid sheets, pots, twine, etc.)	LDPE, PP, PS, HDPE, PRFV, PVC, PMMA	-	Coloured pigments

Table A2. 2: Share of different plastic types used in agricultural applications, 2019[277]

CROP PRODUCTION	
Share of type	**Quantity (kt)**
Share of conventional agri-plastics	**312**
Share of bio-based agri-plastics[278]	5
Share of oxodegradable plastics	8
TOTAL	**325 kt**
LIVESTOCK PRODUCTION	
Conventional agri-plastics	**397 kt**

Table A2. 3: Estimated annual sales in EU of main agri-plastic applications[277]

Applications	Quantity (kt)
Films	533.3
Nets	40
Twines	54.5
Pipes	80
TOTAL	**707.8 kt**

Table A2. 4: Estimated annual sales in EU of agri-plastic applications for crop production, 2019[277]

CROP PRODUCTION	
Applications	**Quantity (kt) Source(s)**
Greenhouses	117
Small tunnels	56.3
Mulching films	77

[277] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics

CROP PRODUCTION	
Applications	**Quantity (kt)** **Source(s)**
Irrigation pipes	20
Drippers	20
Non-woven nets (for collection)	5
Protective nets	4.5
TOTAL	**310**

Table A2. 5: Estimated annual sales in EU of agri-plastic applications for livestock production, 2019[279]

LIVESTOCK PRODUCTION	
Applications	**Quantity (kt)**
Silages	121
Stretch film	146
Bale net	50
Twine	80
TOTAL	**397 kt**

Table A2. 6: Volume of polymers used in conventional and biodegradable agri-plastic applications

Polymers	Quantity (kt)	Source(s)
HDPE	533.3	APE Europe[279,280]
LDPE	54.5	
PP	80	
PE	40	
TOTAL CONVENTIONAL POLYMERS (2019)	**707.8 kt**	

[279] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics
[280] Data provided by APE Europe

Table A2. 7: Estimated annual sales of agricultural films per country (EU+NO/CH/UK/IS), 2018[281]

EU (+ Norway, Iceland, UK, Switzerland), 2018 (ktonnes)			
Spain	93	**Hungary**	8.5
Italy	89.5	**Check Republic**	7.8
Germany	70	**Switzerland**	3.65
France	57.5	**Portugal**	3.4
UK	32.	**Iceland**	1.6
Poland	23	**Estonia**	1.3
Holland	19.5	**Lithuania**	1.3
Ireland	15.6	**Latvia**	1.2
Sweden	13.8	**Slovakia**	1
Belgium	14.31	**Slovenia**	0.95
Finland	11.8	**Romania**	0.9
Bulgaria	9.75	**Luxembourg**	0.6
Greece	9.8	**Malta**	-
Austria	5.8	**Cyprus**	0.35
Norway	8.8	**Misc.**	20
Denmark	7.2		
TOTAL EU + 4 =		**53k kt**	

Source: APE Europe

[281] APE Europe website: “Statistics: Plasticulture in Europe”. Accessible at: http://apeeurope.eu/statistics

Table A2. 8 summarises general requirements as well as specific provisions in existing EU legislations relevant to EPR and/ or agri-plastics recycling.

Table A2. 8: Relevant provisions in existing EU legislation related to agri-plastics

General provisions	Provisions specific to agri-plastics
Waste Framework Directive	
• Concepts and definitions related to waste and EOL practices • Requirements and guidance on establishment of EPR schemes • Introduction of the waste management hierarchy	• Publication of guidelines for the management of construction waste • Recognition of EPR as a key instrument for resource efficiency, and publication of guidelines for the implementation of EPR in MS
EU Plastics strategy for the Circular Economy	
• Accelerate transition towards a circular economy and sustainable economic growth • Harmonisation of EPR schemes in EU • By 2030, plastic packaging on the EU market is recyclable or re-usable and in a cost-effective manner • Minimise plastic waste at source	• Increased share of products made with recycled content • Leadership in sorting and recycling technologies, with global demand for more sustainable ways of processing end-of-life plastics. • Encourage voluntary industry pledges
REACH Regulation	
• Protection of human health and the environment • Enhance competitiveness of EU chemicals industry	• Applicable to recyclers and use of recycled materials • Restrictions on the use of legacy additives in recyclate

Table A2. 9 summarises some of the planned initiatives and other best practices identified at EU and MS level in regard to management of agri-plastic waste.

Table A2. 9: Summary of planned initiatives on agri-plastics

Geo scope	Planned initiatives
EU	• European standard EN 17033 was published in 2018 on the biodegradation of plastic mulch films, specifying test methods and evaluation criteria for the biodegradation, ecotoxicity, film properties and constituents. It uses the existing certification "OK Biodegradable soil" as a basis, which requires 90 per cent CO2 conversion within 24 months in a soil biodegradation test. It also includes a new ecotoxicity testing and evaluation scheme, which considers the impact on plants, invertebrates (e.g. earthworms) and microorganisms. The standard defines restrictions on potentially harmful constituents such as regulated metals and substances of high concern. • The LabelAgriWaste (Labelling Agricultural Plastic Waste for Valorising the Waste Stream) programme is a European research project aimed at developing an economically viable scheme for the collection and valorisation of agricultural plastic waste (APW) destined for recycling or energy recovery. A labelling scheme for APW was designed, tested and improved through a series of pilot tests. • The GLOBAL G.A.P Certificate is a certification scheme, created by European supermarket chains, which provides 'Good Agricultural Practices' for crops, aquaculture, and livestock and horticulture production. It is one of the largest certification schemes of its kind, counting over 188,000 certified producers in more than 125 countries. Some of the criteria set by the initiative include the identification of waste products and pollution sources stemming from all farm areas, including plastics; application of a farm waste management plan to avoid and/or minimise wastage and pollution, with provisions for waste management; and annual risk assessment of physical and chemical pollution of water used for pre-harvest activities, including risks posed by plastics bags.
Finland	The recently adopted Plastics Roadmap in Finland is expected to drive increased recycling in coming years by improving collection services and encouraging innovation. For example, sorted silage films have been allowed to be recycled since the beginning of 2020 and mechanical recycling is being supplemented with chemical recycling, which will enable the utilisation of difficult to recycle, contaminated and mixed plastics.
France	• In France, efforts are being made to improve the practices of depositing and collecting mulch films in the field with the installation of machines at farm level. A decision support tool has been developed to explain the benefits of biodegradable films for certain crops, including lettuce. • ADIVALOR and the French Committee of Plastics in Agriculture (CPA) have also set objectives to achieve 100% collection rate. • The CLEANFILM project, announced at the start of the year, aims to create a pre-treatment unit (grinding-cleaning) for mulch films, which will make these contaminated films recyclable.

Geo scope	Planned initiatives
Greece	The first "Food Innovation and Incubation Center" a local not- for- profit organisation led by the 'New Agriculture for a New Generation' is currently being developed in Greece. The main objective of the initiative is to provide practical support to businesses at both scientific and technical level, as well as in business operation, such as research and development, new product development, market analysis and research and exports. The Center is designed to enhance the capacity of young farmers and entrepreneurs to develop and market new products, as well as to create new unused markets and opportunities. That is to say, it will provide useful and practical knowledge that will help young entrepreneurs develop sustainable careers / businesses in the fields of agriculture, food and other related fields, as well as develop value added agricultural products. Some of the planned tasks include: • Supporting better collection / transportation / management and recycling of agri-plastics & certification to farmers: a) pilot scheme for empty pesticide containers by ESYF / Greek Association for Plant Protection & b) Pilot scheme for agricultural films by Plastika Kritis, and • Developing educational, information & awareness raising activities: a) "New Agriculture for a New Generation" program, b) Hellenic Crop Protection Association (ESYF), c) Stevia Hellas Coop and d) Venus Growers Agricultural Cooperative. The above is supported by 1) A. C. Laskaridis Charitable Foundation (ACLCF), 2) Captain Vassilis & Carmen Constantakopoulos Foundation, and 3) Ministry of Rural Development & Food.
Ireland	IFFPG is exploring the option of increasing/ incentivising the recycled content in agricultural plastics through the application of eco-modulation or levy rebate.
Spain	• In Spain, the use of biodegradable mulching film is one of the environmental actions included in the Real Decreto 533/2017 that could be included in the operational programmes established in Regulation (EU) No 1308/2013 for the vegetable and fruit sectors. As such, Spanish producer organisations in the fruit and vegetables sectors can make use of these operational funds, but as a joint financial instrument, whereby a financial contribution is requested from the producer organisation. Within this scheme, the EU grants for biodegradable mulching equals 25% of the market price. • Green World Compounding has just enlarged the recycling capacity of its plant in Murcia, from 22,000 tonnes/year to 100,000 tonnes/year. This new plant is the largest APW recycler in Europe and has the capacity to potentially handle all the APW generated in Spain. It recycles both greenhouse films and mulching film. It collects APW from large farms as well as use intermediate waste collectors for small farms. The firm received some public funding of the regional government to support the creation of strategic companies of the agricultural sector. The new plant counts with a line to recover the soil attached mainly to the mulching film and prepares it to be used as aggregate.
Sweden	SvepRetur aims to collect 70% of the plastic used in agriculture. Of all the plastic gathered at least 30% should be recycled, i.e. channelled back into the manufacturing of new products. The remainder goes to energy recovery, which means combustion where the energy is used for heating and electricity.

A.2.1.1 Bio-based and Biodegradable Plastics World Market

Bio-based plastics are used in an increasing number of markets, from packaging, automotive, agriculture/horticulture and toys to textiles and a number of other segments. Packaging remains the largest field of application of these materials with more than 53% (1.14 million tonnes) of the total bio-based plastics market in 2019, while volumes intended for agriculture/horticulture sector represents 161 kt worldwide[282]. The European market share is unknown.

Currently, bio-based plastics represent about 1% of the more than 359 million tonnes of plastic produced annually.[283]But as demand is rising, and with more sophisticated polymers (e.g. multilayer plastics, plastics with innovative additives, etc.), applications, and products emerging, the market for bio-based products is continuously growing and diversifying. According to the latest market data compiled by European Bioplastics, bio-based plastics global production capacity accounts for 2.11 million tonnes in 2019, of which Europe represents 25%[284]. In regard to the agricultural sector, 3% of global market share of bio-based polymers is allocated to this sector, with a focus on the development of biodegradable mulch films. In fact, 99% of plastics either bio-based or fossil-based used for agricultural purposes are biodegradable. [285]Global bio-based plastics production capacity is set to increase from around 2.11 million tonnes in 2019 to approximately 2.43 million tonnes in 2024 especially due to PHA's significant growth rates. [286]

The use of **biodegradable plastics**, on the other hand, is not currently widespread in the European agricultural sector due to a variety of factors including their cost in terms of market price, which can be significantly higher compared to conventional plastics Other factors may include the perception that biobased or biodegradable plastics have negative impacts on soil quality as well as regional climatic conditions. These factors were cited as the main reasons why farmers in Finland are not using biodegradable plastics to a larger extent. Not only can the price of bio-based and biodegradable plastics cost up to three or four times higher than conventional plastics, but horticulture producers in Finland are also concerned about the effects of biodegradable plastics on their fields.[287] Further, it was also reported that weather conditions in Finland (cold winter and soil) are not favourable for the use of biodegradable films, where in general, mulch films for example, can typically be used for longer periods – up to 3 or 4 seasons (years), compared to other European countries with milder weather conditions, where

---

282 European Bioplastics, Nova-Institute (2019) Bioplastics market data 2019. Available at: https://docs.european-bioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2019.pdf

283 Michael Carus, Nova-Institute (2019). Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2018 – 2023

284 European Bioplastics, Nova-Institute (2019) Bioplastics market data 2019

285 European Bioplastics, Facts and figures. Available at: https://docs.european-bioplastics.org/publications/EUBP_Facts_and_figures.pdf

286 European Bioplastics. New market data 2019: Bioplastics industry shows dynamic growth.

287 Based on questionnaire responses and interview with Brahea Centre – University of Turku, April 2020

they may be used for shorter periods i.e. only for 2 seasons.[288] In France, additional efforts are being carried out by the collection scheme ADIVALOR to increase the awareness of farmers using a decision support tool that was developed to explain the benefits of biodegradable films for certain crops, including lettuce.[289]

Box A2. 1: examples of European research projects on biodegradable plastics

During the past few years, several European research projects have been conducted to develop biodegradable plastics for mulch films. The main projects have been launched in Spain (EA (2001-2002), TRIGGER (2003-2005), and MULTIBIOSOL (2016-2019)), in Greece (BIOPLASTICS (2001-2005), BIODESOPO (2007-2009)), in Portugal (AGROBIOFILM (2010-2013)) and in Italy (BIOMASS (2003-2006)). Their objectives were mainly to optimize and develop new plastics by making them fully biodegradable and compostable in order to reduce soil contamination by plastic pollutants and to study the biodegradability of plastics in soil. For example, the aim of MULTIBIOSOL project launched in 2016-2019 was to demonstrate that the use of biodegradable plastics can make agricultural practices sustainable and efficient.

A.2.2 EU Country Level Analysis

A.2.2.1 Finland

Existing measures and EOL management

In October 2018, the Finnish Ministry of the Environment adopted the national Plastics Roadmap. Promoting the recycling and replacement of plastics in agriculture are among the key measures proposed.[290] A dedicated collection scheme for agri-plastic waste is not currently established in Finland. Instead, EOL management operations are carried out via a cooperation network, which includes collection services.

Plastic packaging used in agriculture are subject to producer responsibility requirements if the packaging of products is professionally placed on the market, whereas plastics used for packaging feed on farms are excluded. There are reception terminals established by producers where plastic packaging waste can be delivered free of

[288] Based on questionnaire responses and interview with Brahea Centre – University of Turku, April 2020
[289] Based on questionnaire responses and interview with ADIVALOR, April 2020.
[290] Finnish Ministry of Environment (2018). A Plastics Roadmap for Finland; Available at: https://muovitiekartta.fi/userassets/uploads/2019/03/Reduce-and-refuse-recycle-and-replace.-A-Plastics-Roadmap-for-Finland.pdf

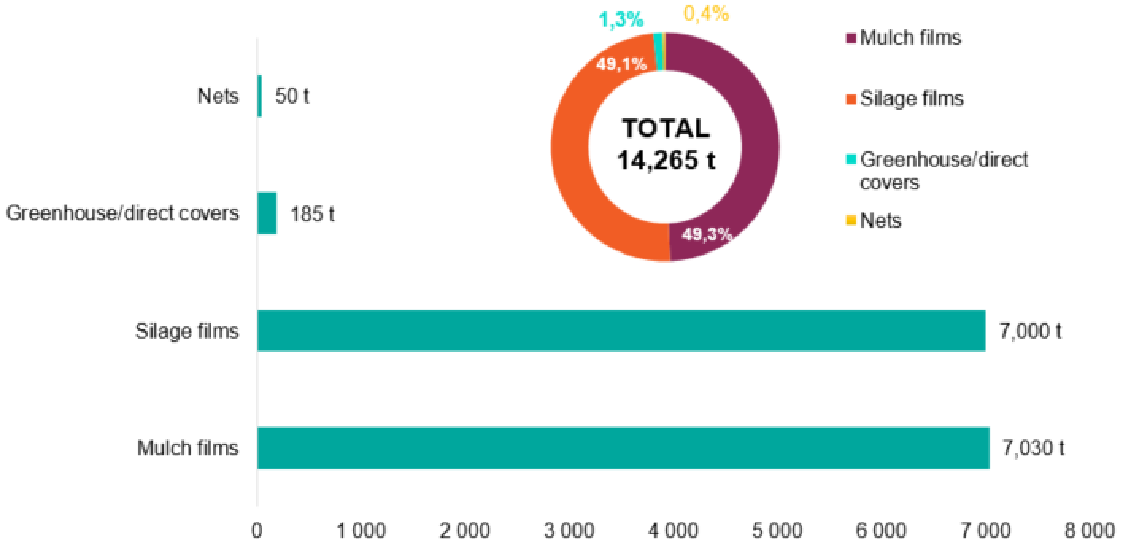
charge.[291] The main actors involved during the EOL phase of agri-plastics in Finland include recyclers (Clean Plastic Finland Ltd), farm retailers, waste management operators (regional and national), as well as heating and energy recovery companies.

Agri-plastics consumption

In 2019, an estimated 14,265 tonnes of agri-plastic applications were placed on the market in Finland (see Figure A2. 1). Mulch and silage films represent the largest share of the market (98%), followed by greenhouse and direct covers and nets for crop production e.g. strawberries and vegetables.[292]

Figure A2. 2 presents the share of the main polymers used, of which LPDE for the production of mulch films represents the largest share (98%) of the market. In regard to the use of biodegradable plastics, which in 2019 represented only 0.21% of the market, the comparatively high cost of biodegradables prevents their more wide-spread use.

Figure A2. 1: Quantity of agri-plastic applications (excl. packaging) placed on market in Finland, 2019 (tonnes)

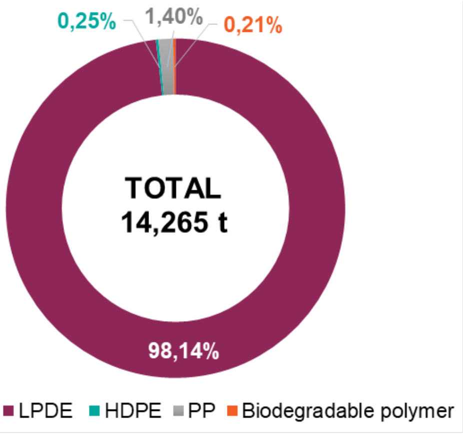


Source: Turku University

[291] Finnish Ministry of Environment (2019) A Plastic Roadmap for Finland. Available at : https://muovitiekartta.fi/userassets/uploads/2019/03/Reduce-and-refuse-recycle-and-replace.-A-Plastics-Roadmap-for-Finland.pdf

[292] Based on questionnaire responses and interview with Brahea Centre – University of Turku, April 2020

Figure A2. 2: Share of main polymers used in agri-plastics in Finland, 2019

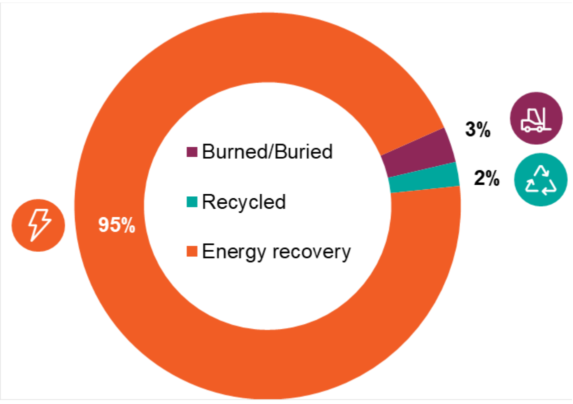


Source: Turku University

Agri-plastic waste generation and end-of-life practices

Approximately 12,000 tonnes of agri-plastic waste (including packaging) is generated annually in Finland.[293,294] Silage films constitute by far, the main waste stream, followed by mulching films and agri-plastic packaging. Based on available data from literature and stakeholder feedback, the majority of (non-packaging) agri-plastic waste is treated via energy recovery (90-95%), while only about 2% is recycled and the rest (3%) burned on site or buried in soil (Figure A2.3).

Figure A2. 3: EOL treatment of APW (excl. packaging) in Finland (annual average)



The relatively small amount of (non-packaging) APW collected and recycled stems from the preparation process needed for collection (due to the different types of plastics used), high contamination, particularly for silage and mulching films, high collection costs and the distance between farms and waste treatment centres.

Consequently, a potentially significant amount of APW is not being collected and instead stored on farms (and in some cases, burned or buried on site). As such, further improvements of the existing waste management system are needed in

[293] Horttanainen, Mika et al. (2007) Recycling of Plastic Waste of Farms
[294] Based on questionnaire responses and interview with University of Turku, April 2020

order to increase recycling.[295] To this end, the new Plastics Roadmap in Finland is expected to drive increased recycling in coming years by improving collection services and encouraging innovation (see Table A2.9 for additional details).

Market trends and EOL treatment costs

The use of biodegradable plastics in agriculture is currently limited in Finland due to higher market prices—which can be up three or four times higher than conventional plastics (Table A2. 10), regional weather conditions, and the perceived negative impacts by farmers on soil quality.

Table A2. 10: Estimated market prices of mulch and silage films in Finland

Agri-plastic applications	Type	Price (EUR)
Mulch film	Conventional (LDPE)	141 €/roll 50 kg
	Biodegradable	362 €/roll 50 kg
Silage films	Conventional (LLDPE)	77 €/roll 30 kg

Source: University of Turku

In regard to collection costs for APW, costs can range from €30 to €120/tonne depending on a wide range of factors from the degree of contamination, sorting required and distance from farms to waste management centres, etc.[296]

A.2.2.2 France

Existing measures and EOL management

In France, (non-packaging) agri-plastic waste is managed through a **voluntary collection scheme**, operated by the producer responsibility organisation (PRO) ADIVALOR. The scheme was established in 2001 by the French Committee for Plastics in Agriculture (CPA). In addition to the scheme, other private companies are also involved in the collection of agri-plastics waste in France.

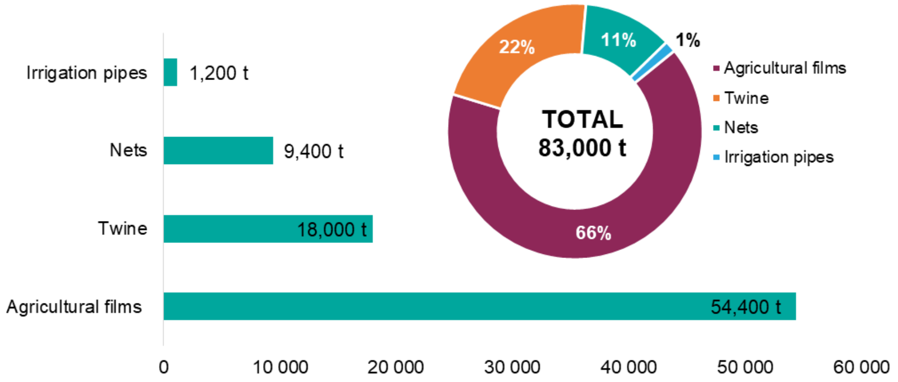
Agri-plastics consumption

In 2019, an estimated 83,400 tonnes of agri-plastic applications (excluding packaging) were placed on the French market.[297] Agricultural films accounted for the largest share (66%), followed by twine (22%), nets (11%)[298] and flexible irrigation pipes (1%) (see Figure A2. 4). Of this amount, approximately 80 % (16,500 tonnes) is used for livestock production and the remaining 20% for crop production (See Figure A2. 5).[299]

[295] Finnish Ministry of Environment (2018). A Plastics Roadmap for Finland
[296] Based on questionnaire responses and interview with University of Turku, April 2020
[297] French Committee for agricultural plastics (CPA) (2019) Annual report
[298] Nets including anti-hail nets, accounting for approximately 900 tonnes
[299] French Committee for agricultural plastics (CPA) (2019) Annual report

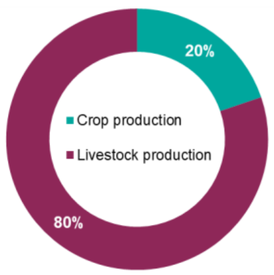
In regard to the main polymers used, LDPE accounts for the largest share placed on the market (66%), followed by PP (22%), HDPE (11%) and LLDPE (1%) (Figure A2. 6).

Figure A2. 4: Quantity of specific agri-plastic applications placed on market in France, 2019 (tonnes)



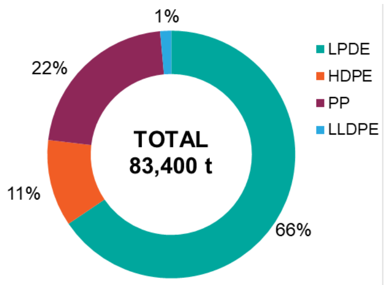
Source: CPA

Figure A2. 5: Distribution of agri-plastics consumption in France by market segment, 2019



Source: CPA

Figure A2. 6: Share of main polymers in agri-plastics in France, 2019

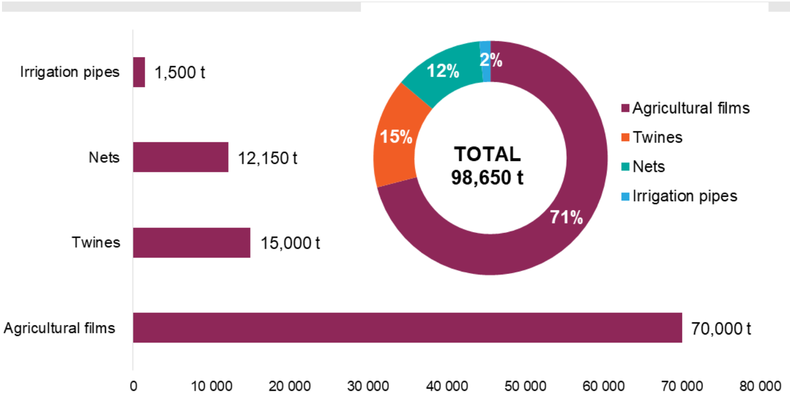


Source: CPA

Agri-plastic waste generation and end-of-life practices

In 2019, approximately 98,650 tonnes of APW (excluding packaging) were generated in France (Figure A2. 7).[300] Agricultural films accounted for 71% of APW, corresponding to reported consumption trends (66% of market).

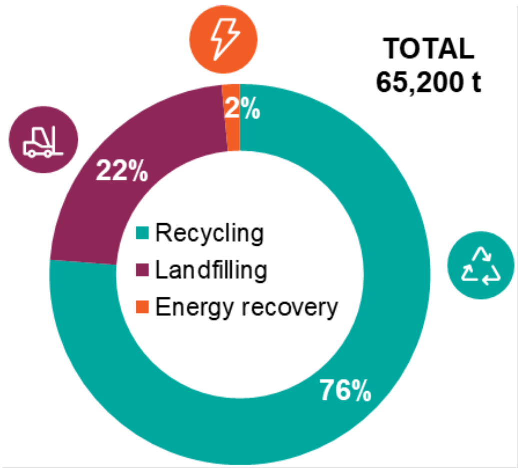
Figure A2. 7: Quantity (tonnes) of APW (excl.packaging), by application in France, 2019



EOL treatment figures are based on data obtained from ADIVALOR. The scheme currently only covers agricultural films, nets (including anti-hail nets), twine and irrigation pipes (flexible). As such, data on EOL practices (Figure A2. 8) are based on the total quantity of APW collected by the scheme.

In 2019, 65,700 tonnes of APW were collected by ADIVALOR. This corresponds to an estimated 67% collection rate in respect to the total amount of APW generated. Of the quantity collected, 76% was recycled, 22% was landfilled, and 2% was used for energy recovery (Figure A2. 8). Agricultural films were the only applications sent for landfill (14,494 tonnes) and energy recovery (1,000 tonnes). Concerning recycling, 79% (42,000 tonnes) of the agricultural films collected were recycled, and 100% of nets, twines and irrigation pipes collected were recycled. The French recycling rate for APW based on APW generated is around 50%.

Figure A2. 8: EOL treatment of APW collected in France, 2019 (tonnes)



Source: ADIVALOR

According to the collection scheme, the significant difference between the volume placed on the market and the volume collected and recycled is due to high contamination (in particular for mulch films and products used to collect and store feedstock). Minimum contamination

[300] Based on questionnaire responses and interview with ADIVALOR

level is estimated to be on average 20% (and up to 50% for mulch films).

Market trends and costs

On average, EOL treatment costs in France are as follows:[301]

- Landfill: €135/tonne
- Energy recovery: > €100/tonne
- Collection: €0 to €250/tonne (depending on characteristics of the waste stream (e.g. weight, density, etc.) and quantity of plastic/per m^3 transported i.e. transported from collection points to pick-up by the final processing unit.

A.2.2.3 Germany

Existing measures and EOL management

In Germany, a **voluntary collection scheme** for agri-plastic waste has been established since July 2013. It is operated by the producer responsibility organisation, ERDE (Erntekunststoffe Recycling Deutschland).[302,303] Landfilling on site on farms of agri-plastic waste is not allowed in Germany.[304]

Agri-plastics consumption

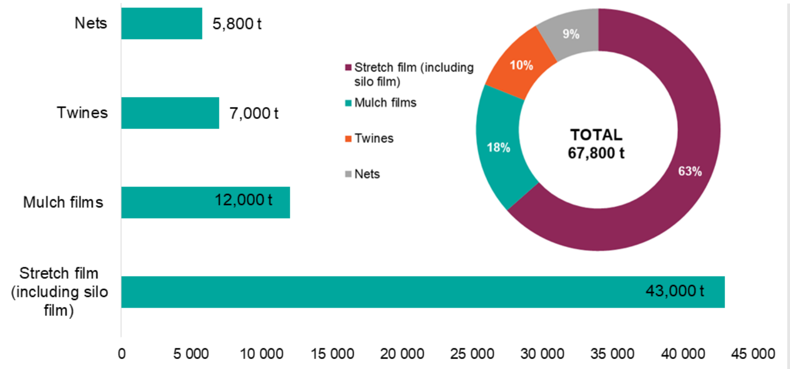
Reported data on the market share and volume of the main agri-plastic applications used in Germany vary depending on the source due to scope, year, etc. of data reported. Estimates based on data from Conversio (2018) indicates that in 2019, approximately 67,800 tonnes of agri-plastic applications (excluding packaging) were placed on the market in Germany (see Figure A2. 9).[305] Stretch films (including silage films) accounted for the largest share at almost 43,000 tonnes (63%), followed by mulch films (18%), twines (10%) and nets (9%). These figures correspond more or less to market estimates based on collection data reported by ERDE: in 2019, the 20,500 tonnes of stretch and silage film collected corresponded to over 40% of the total market volume, amounting to at least 51,250 tonnes.[306] The type of polymers predominantly used in agri-plastic applications in Germany is LPDE (78%) (Figure A2. 10). Around 2,000 tonnes of biodegradable polymers are used in Germany, which represents only 3% of the total of polymer types used. However, other alternative products including biodegradable agri-plastics are also put on the German market. There are several manufacturers of

---

[301] Based on questionnaire responses and interview with ADIVALOR
[302] ERDE website, accessible at : www.erde-recycling.de/en/about-erde/what-is-erde.html
[303] PlastEurope website on Agricultural Film Recycling. Accessible at: www.plasteurope.com/news/AGRICULTURAL_FILM_RECYCLING_t236996
[304] Based on questionnaire responses submitted by UBA, March 2020
[305] Conversio (2018) Material flow of plastics in Germany in 2017. Available at: www.bkv-gmbh.de/fileadmin/documents/Studien/Kurzfassung_Stoffstrombild_2017_190918.pdf
[306] ERDE website accessible at: www.erde-recycling.de/en/faq/faq-en.html

biodegradable materials according to EN 17033 (certified by DIN certco[307]) in Germany include: Novamont S.p.A.: Mater-Bi EF04P, Mater-Bi EF08P0, Mater-Bi EF08P1; BASF SE: ecovio M2351 and Sichuan Kai Yuan Chuang YI Biological Technology Co., Ltd.: mulch film.

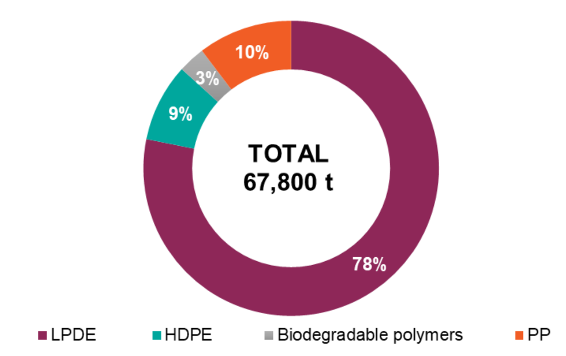
Figure A2. 9: Quantity of specific agri-plastic applications placed on market in Germany, 2017 (tonnes)



Source: Own estimations[308]

There is no quantified data and detailed information available on the use and the particular challenges related to the use of recycled agri-plastics in Germany. For the German Environmental Agency (UBA), the main challenges are to ensure the particular proprieties of agri-plastics such as UV-resistance, water permeability, antifogging, colour, anti-static effects and defined thickness regarding to the purpose, etc.

Figure A2. 10: Share of main polymers used in agri-plastics in Germany, 2017



Agri-plastic waste generation and end-of-life practices

The operation of ERDE's collection scheme is based on the principle of shared responsibility between all agro-supply professionals. A total of 68 partners operated 408 collection points in 2018.[309] The main actors involved in the collection scheme include:

---

[307] Dincertco website on biodegradability. Accessible at : www.dincertco.de/de/dincertco/produkte_leistungen/zertifizierung_produkte/umwelt_1/biodegradable_in_soil/biodegradable_in_soil.html

[308] Based on data received from UBA and Federal statistics office

[309] PlastEurope website (16 April 2019). "Agricultural Films Recycling: Germany's Erde initiative almost doubles collection volume". Accessible at: www.plasteurope.com/news/detail.asp?id=242253

- **Professional users**, mainly farmers, sort, prepare and bring their waste on the dates and places fixed by their collection operators. Every supply agency and farmer that uses the products can dispose of their used crop plastics at an ERDE collection point.
- **Collection operators**: Every company that collects plastics integrated in ERDE (Co-ops, private agricultural trades and machinery rings, waste management companies) can become an ERDE collection point. Year-long or for the period of one or two days, they take back the swept clean crop plastics.
- **Manufacturers participating to the recovery concept** include, among other, APE Europe, ASPLA S.A., Groupe Barbier, bpi agriculture, TRIOPLAST GmbH, etc. Every manufacturer or original distributor of films that supplies the German market can become a member of ERDE. IK Industrievereinigung Kunststoffverpackungen e.V. is the German association for plastics packaging and films, gathering 300 member companies. The association promote the recovery and recycling of crop plastics. It is taking an active responsibility for the handling of their products.

- In Germany, agri-plastic waste is collected separately by groups:
  - **Group 1:** silage sheets, under layer films and silo tubes ;
  - **Group 2:** silage stretch films and net replacement films ;
  - **Group 3:** round bale nets.

Films must be swept clean and be free of coarse dirt. No foreign materials, such as iron, wood, tires and no yarn or netting may be mixed up in the films. Round bale nets must be separated into bags. The bags are distributed via the collection point.[310] The collected plastics are reduced to small pieces, washed and melted down into regrind (recycling) to then be used in countless plastic products.

Agri-plastics waste are collected locally and treated by specialised treatment facilities located in Germany and in third countries. Foils collected under the ERDE take-back system go for mechanical recycling. Agricultural plastics such as packaging for hazardous substances (e. g. pesticides or fertilisers) and non-hazardous substances collected under the RIGK take-back system are (if possible) mechanically recycled or sent for energy recovery. Part of the waste is disposed of as residual waste and is sent for energy recovery (incineration).

Key figures on EOL practices in Germany are based on data obtained from ERDE, which cover silage and stretch films, nets and twine – the main APW streams collected by the scheme. These agri-plastic applications are also the main ones placed on the market.

In 2019, ERDE collected and recycled almost 20,500 tonnes of stretch and silage film, corresponding to over 40% of the total market volume (51,250 tonnes).[311] How the

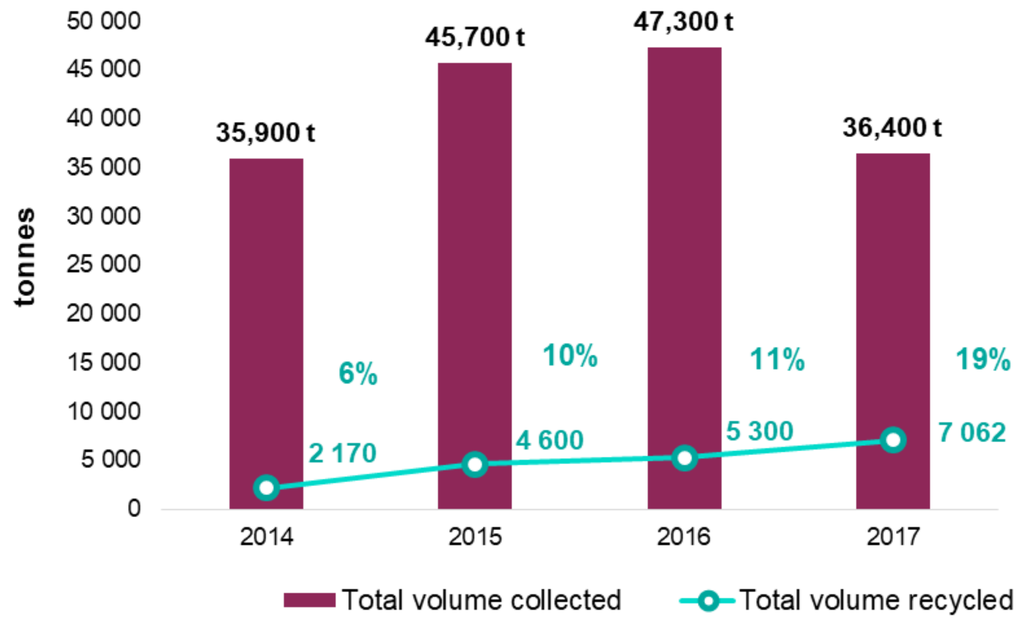
---

[310] ERDE Recycling Brochure (n.d.). Accessible at: www.erde-recycling.de/fileadmin/user_upload/interner_Bereich/20200201_RIGK_ERDE_Falzflyer_EN.pdf
[311] ERDE website accessible at: www.erde-recycling.de/en/faq/faq-en.html

remaining APW is treated is unknown. However, landfilling on site on farms is not allowed in Germany.

As shown in Figure A2. 11, from 2014 to 2017, the recycling rate of collected silage and stretch films have steadily increased each year. ERDE aims to further increase collection and recycling rates of silage and stretch films marketed in Germany to 50% by 2021 and 65% by 2022. The recycling rate of the total volume waste generated increased by 1% between 2015 and 2017 (2% to 3%).

Figure A2. 11: Quantity of agri-plastics collected and recycled in Germany from 2014 to 2017 (tonnes)



Source: ERDE

A.2.2.4 Greece

Existing measures and EOL management

In Greece, the National Waste Management Plan 2015-2020[312], (which is currently being revised and expected to be completed by mid-2020), makes specific provisions in regard to agricultural waste (including all agri-plastics). The Ministry of Energy and Environment (with support from the Ministry of Agricultural Development and Food) is in the process of drafting a "Joint Ministers Decision" that will enforce producers' responsibility according to EU Directives and national legislation. It will provide the legal framework for the establishment of an EPR scheme for agricultural film producers: ''Alternative Waste Management System". In 2020, the 'New Agriculture for a New Generation' pilot programme was also launched and aims to disseminate and exchange views with local

[312] Greek Ministry of Environment and Energy website, accessible at: www.opengov.gr/minenv/?p=6644

communities, agricultural cooperatives and producers in order to gradually create a circular economy model for agricultural plastics (see also Table A2.9).

In regard to the EOL management of agri-plastic waste, there is currently no established collection scheme at national or regional level in Greece. However, two pilot schemes for pesticide plastic packaging waste and greenhouse films are currently in operation, providing additional insights on how specific APW streams are being managed.

The main national legislations covering agri-plastics in Greece include:

- The Greek Law 2939/2001 which incorporates Directive 94/62/EC on packaging and packaging waste and Law 4496/2017 (which revises L.2939/2001)
- The Ministerial Decision 106453/2003 (ΦΕΚ 391/Β/2003) concerning the Collective Alternative Management System for packaging waste (CAMS – RECYCLING) of the Hellenic Recovery Recycling Corporation (HERRCO). According to above MD 106453/2003, companies in the pesticide industry are included in this EPR system (CAMS – RECYCLING of HERRCO)
- The Greek Law 4036/2012 concerning pesticides - Pesticide marketing, sustainable use and other provisions, in particular Article 27 concerning the management of pesticide packaging
- Joint Ministerial Decision 8197/90920/2013 (revised by JMD 6669/79087/2015) concerning the National Action Plan about the proper use of pesticide products, in particular Article 29 concerning the proper management of pesticide plastic packaging products

Agri-plastics consumption

Accurate data is not available on the quantity of specific (non-packaging) agri-plastic applications placed on the market in Greece. However, based on estimations from input provided by the Hellenic Crop Protection Association (HCPA), on average, 8,500 tonnes of agricultural films are placed on the market per year (See Figure A2. 12). Agricultural films can be further broken down as follows in regard to the quantity of specific applications placed on the market:[313,314]

- Greenhouse films, wine & tobacco covers = 3,600 tonnes/year
- Low-tunnels and fumigation films = 1,900 tonnes/year
- Mulching films = 2,000 tonnes/year
- Bale wrapping = 500 tonnes/year
- Silage = 500 tonnes/year

All of the above product types are made of polyethylene & EVA materials. Very limited information is available concerning trends on the use of biodegradable vs conventional

---

313 Plastika Kritis (n.d.). Available at: www.generationag.org/assets/site/public/nodes/1142/1468-3-Manos-Kyrkilis-Plastika-Kritis.pdf?fbclid=IwAR3txWMsh9y2dCaDuKfrR5NKhP8lhzsq_AusAbF2IAF-Zk18n_tSsvcGfhI

314 Estimated based on input provided by HCPA.

plastics in agriculture as biodegradable plastic products have a very high cost of production and as such are not widely used in Greece.

In Greece, the majority of agricultural plastics produced and placed on the market include agricultural films and pesticide plastic packaging containers. Other agri-plastic applications such as ropes, nets and plastic pipe systems are also manufactured, however at much lower scales and where very limited data is currently available at national level via the National Producers' Registry.[315]

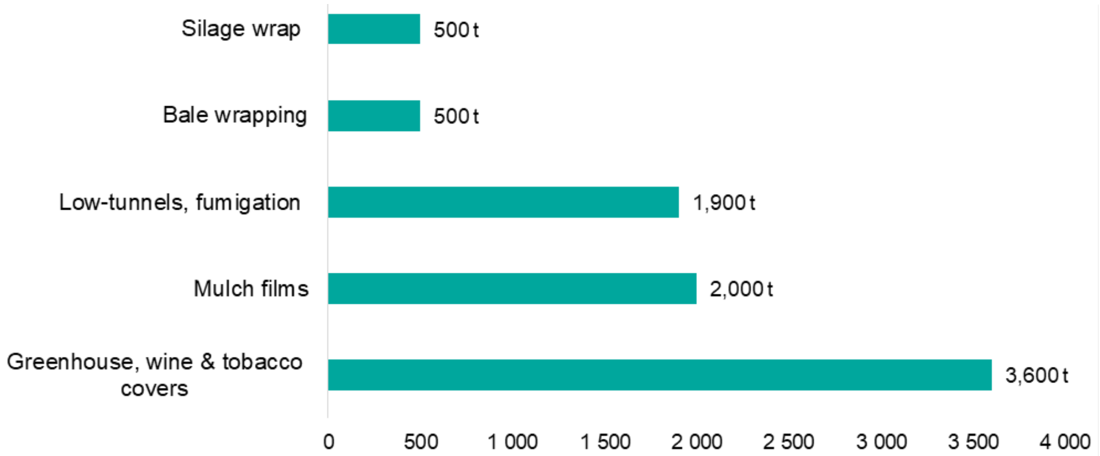
The main agri-plastic applications and estimated volumes placed on the market in Greece include:

1) Agricultural films (8,500 tonnes)
2) Empty containers of pesticide products/packaging (1000 tonnes)
3) Old Irrigation parts
4) Parts from agricultural equipment

Categories 1 & 2 account for approximately 9,500 tonnes.

According to HCPA, production quantities of pesticide plastic packaging products are almost similar to the quantity consumed/placed on the market at 800 tonnes/year (on average). The majority of pesticide packaging products are manufactured with PE and to a lesser extent materials used COEX (5-10%) and PET (<1-2%).[316] It should be noted that biodegradable material is not used for pesticide plastic packaging products due to UN standards for safety requirements (leakage).[317]

Figure A2. 12: Average volumes of agricultural films placed on market in Greece (tonnes)



[315] https://www.eoan.gr/en/content/17/national-producers-registry
[316] Interview with HCPA, March 2020.
[317] Interview with HCPA, March 2020.

Source: Own estimations

The main key players identified in the agri-plastics supply chain in Greece are presented in the following table:

Table A2. 11: Key stakeholders of agri-plastics sector in Greece

Name	Relevance
ACHAIKA PLASTICS S.A.	The company **uses Polyethylene LDPE and HDPE as raw material**, to produce the wider range of flexible plastics (packaging) for Greece. Heat-shrinkable film for automatic packaging, industrial bags, mainly for the fertilizer industry, plastic bags, drawstring rubbish bags, agricultural polyethylene films and palletizing films.
BASF	BASF provides a full range of solutions for the agriculture industry • Greenhouse Films • Mulch Films • Silage Films and Stretch Films
EURODRIP ABEΓE	Irrigation pipes producer Plastic Pipe Systems producer
EUROFILM MANTZARIS AE	**Flexible packaging producer:** • Low Cover (mulch film) • Green House Film • Agricultural Plastics Covers • Plastic Films for Agricultural and Industrial Use
DAIOS PLASTICS AE	• Soft Fruit Protection / Safe-D used for Safe-D is used for soft fruit applications such as table grapes, cherries, raspberries, blueberries, blackcurrants among others. • Greenhouse films • Special Films for Greenhouses (Air – Tube: A special tube for transferring the warm air in the greenhouse house was developed by the team of Daios Plastics) • Greenhouse Sides: a welded part on the top of the film encloses a rope, which allows the farmer to apply the film on the side of the greenhouse very fast without wasting money and time.
THRACE PLASTICS Co S.A	**Thermoforming – mainly PP, PE and HDPE** • Groundcovers • weather protection covers, • foliage removal fabric (white polypropylene woven fabric), • heavy duty frost protection (polypropylene needle punched nonwoven fabric), • mulching (100% polyethylene), • crop cover (polypropylene needle punched nonwoven fabric), • nets (produced from 100% HDPE), • ropes & twines (extruded multifilament polypropylene yarns)

PLASTICA KRITIS ABEE (35% of the market share)	• Greenhouses • New 7-layer greenhouse films • Low-tunnels • Mulching • Soil-disinfection • Energy-screening • Silage • Silage and grain bags • Farm and animal buildings • Pond-lining KRITIFIL® multi-layer films are manufactured at widths up to 20 m and at thickness down to 10 mic. **Key:** Plastica Kritis recycle agricultural films at their local plant in Crete.
STAMATIOU PLASTICS AEBE	Plastic Pipe Systems producer • Irrigation (drainage) • Pipes & Parts (PE Pipes, PE Parts, PVC – U Pipes, PVC – u Parts)
Other key stakeholders	
Hellenic Crop Protection Association (HCPA), (ΕΣΥΦ)	The Hellenic Crop Protection Association (HCPA) represents companies involved in the pesticide industry (Producers) that produce, standardize and distribute plant protection products in the Greek market. Members of HCPA include about 20-25 companies that represent the majority of the market share in plant protection products in Greece (**85%-95%** of the market share).
Agricultural University of Athens (AUA)	Their research group (Structures & Materials Research Group (SMRG, http://www.smrg.aua.gr/) of the Department of Natural Resources and Agricultural Engineering of the Agricultural University of Athens) has a long experience and expertise on conventional and bio-based agricultural plastics. AUA coordinated two projects on conventional agricultural plastics: LABELAGRIWASTE, "Labelling agricultural plastic waste for valorising the waste stream', Collective research, 516256-2, 2006-2009. AGROCHEPACK "Design of a common agrochemical plastic packaging waste management scheme to protect natural resources in synergy with agricultural plastic waste valorisation" Project No. 2G-MED09-015 ERDF MED Programme, 2009-2013 and several projects on bio-based plastics.
Ministry/Public authorities (e.g. rural municipalities)	The Ministry of Environment and Energy (with support from the Ministry of Agricultural Development and Food) will be leading the revision of the national legislation in order to introduce new EPR schemes for pesticide plastic packaging and greenhouse films (the latter via a Joint Ministerial Decision).
EOAN	The Hellenic Recycling Agency (EOAN) will approve the introduction of two EPR schemes for pesticide plastic packaging and greenhouse films (the latter via a Joint Ministerial Decision).
New Agriculture for a New Generation	Local not profit organisation aims to create career opportunities and entrepreneurship for youth in the Agrifood sector in Greece, facilitating new R&D and business models in the agriculture sector.

Agri-plastic waste generation and end-of-life practices

No available and reliable quantitative data have been identified in regard to agri-plastics waste generation and end-of-life treatment in Greece. As agri-plastic waste management data is not currently reported separately, figures at national level are unavailable. Based on input from key stakeholders, the main EOL practices for APW in Greece include:

- Collected along with municipal solid waste (MSW) and landfilled
- (Illegal) burning

- Limited recycling of agricultural plastics, specifically greenhouse films and pesticide plastic packaging waste.

Inefficiencies in the management of APW in Greece is in part due to the absence of specific national waste management legislation. However, as mentioned previously, this is expected to change following the planned revisions to the national waste legislation, which will introduce new EPR schemes for pesticide plastic packaging and greenhouse films.

In regard to end-of-life treatment costs, greenhouse films made of polyethylene (PE) is estimated to cost 330 €/per hectare (including collection costs).

Pilot scheme for the management of greenhouse films

In Greece there are currently 7 points for the separate collection of greenhouse film, the majority installed in Crete (Ierapetra, Tympaki, Paliochora, and Falasarna). The films collected are currently brought for recycling to Plastika Kriti's facility. Recycling of greenhouse films is carried out in large degree in Crete. There is a second recycling facility in the Peloponnese, Iordanidis S.A. which collects the greenhouse film for recycling at a local plant. Agri-plastics are mono-material therefore, these are made into pellets which are then used for the production of agri-plastic pipes, bags.

The next stage will be to organise in cooperation with regional/local authorities and farmers associations new collection points in Marathon, Manolada, Trifylia, Preveza, Trikala and Imathia covering more areas in Greece.

The introduction of new collection points will involve farmers depositing the greenhouse films in large containers, these will be shredded, baled and then sent for recycling. Plastika Kriti's are investigating the possibility of controlled incineration for energy recovery. There are also currently discussions with the cement industry whether the greenhouse films once they reach their EOL can be incinerated in cement kilns for alternative fuel production.

Some of the key challenges for the successful implementation of the planned EPR scheme for greenhouse films Ministerial Decision include:

- To implement the measures that will be set by the Ministerial Decision, the planned EPR scheme for greenhouse films will have to introduce collection points in additional areas and to identify solutions for remote areas (e.g. islands) or areas with small usage of agricultural films which doesn't justify a separate collection point.
- A significant difficulty will be the appropriate disposal of thin films (mulch, low-tunnels, fumigation, bale-wrapping) which are not suitable for recycling due to heavy contamination. There are no recycling plants for thin films due to the small thickness and very high soil and humidity content after their usage.
- Plastika Kriti's are investigating the possibility of controlled incineration for energy recovery.

- In additions, the collection of silage protection nets is assessed to be impossible due to very high dispersion farms and very small quantities generated per hectare.

Pilot scheme for pesticide plastic packaging waste

Since 2013 a pilot program for the separate collection and recycling of pesticide plastic packaging waste has been implemented by HCPA in collaboration with HERRCO (National EPR scheme for packaging). Company members of HCPA are part of the existing EPR system for packaging (CAMS – RECYCLING of HERRCO). Participants in the pilot program involved (on a voluntary basis) include: municipalities, farmer associations, private companies/producers and local businesses/shops for pesticide products (as collection points). It is possible that the planned new EPR system includes more categories of agri-plastics in the future. The main outputs and planned initiatives of the pilot program are presented in Box A2. 2.

The key challenges for the successful implementation of the planned separate EPR system for pesticide plastic packaging waste include:

- Participation of local businesses/shops that sell pesticide products (as collection points).
- Participation of farmers (obligatory) – Effective monitoring and penalty system
- The lack of proper management of hazardous substances remaining in the pesticide plastic packaging waste
- The lack of necessary infrastructure for the collection of pesticide plastic packaging waste.
- Importance of Awareness/ Information/ Training activities for involved stakeholders (farmers, associations, etc.)

Box A2. 2: Planned initiatives of pilot collection scheme for pesticide packaging waste in Greece

Principal expected outputs:

- 8-10 tonnes/year of pesticide plastic packaging waste collected
- 6.500 farmers trained/ informed on proper EOL management
- Municipalities participating: Killer, Agia, Elassona, Larissa, Tempi, Tyrnavos, Farsala, Veria, Naoussa, Iraklia Serres, Pella, Nigrita, Mouzaki, Palamas, Farkadona, Preveza, Ioannina, Preveza, Ioannina.
- Estimated collection (recycling) rate achieved <10% (estimation based on quantities collected from the region of Larisa region where there is full coverage)
- Collected quantities of pesticide plastic packaging waste are transferred to MRFs, recycled as a separate stream (not mixed with other municipal packaging) and further processed to existing recyclers in Greece (such as Skeberis Plastics)
- Recycled plastic material is used for the production of specific products (such as sewage pipes)

Planned initiatives:

- Development of a separate EPR system for pesticide plastic packaging waste
- HCPA has prepared a 5year Business Plan for the development of a separate EPR system for pesticide plastic packaging waste as well as a feasibility study for the implementation of a DRS for pesticide plastic packaging waste
- According to HCPA, DRS is not preferred in this first stage of development of the new separate EPR system for pesticide plastic packaging, due to legal/financial/administrative difficulties.
- HCPA assumes that the new EPR system will receive approval by the Ministry in May/June 2020.

A.2.2.5 Ireland

Existing measures and EOL management

In 1997, Ireland introduced specific legislation designed to assist and promote the recycling of agricultural plastics (silage wrap, bags, sheeting). As of October 2017, netting and twine have also been included.[318] Ireland is one of the few European countries to have implemented such measures. Producers of the specified farm plastics must:

- Become directly involved in the recovery of farm plastics waste from customers through offering a deposit and refund scheme, or;

---

[318] Waste Management (Farm Plastics) (Amendment) Regulations 2017. Available at: http://opac.oireachtas.ie/AWData/Library3/CCAEdoclaid080917_122641.pdf

- Participate in the collection / recovery scheme operated by the Irish Farm Film Producers Group (IFFPG)

The Irish Farm Film Producers' Group (IFFPG) operate the only EPR scheme for these agri-plastic applications (e.g. silage wrap, bags, sheeting, nets and twines) in Ireland. Currently, there are no producers offering a deposit and refund scheme. As such, all producers are members of IFFPG, Ireland's sole government-approved farm plastics recycling compliance scheme. For farmers not involved in the IFFPG scheme, the alternative options in regard to management of silage wrap and sheeting waste include:

- Use of an independent collector operating separately to the IFFPG scheme.
- Landfill: However, this option is costly as landfill gate fees are €70 to €80 per half a tonne, which is significantly higher than the collection fees charged by IFFPG (see section 0).
- On-farm storage/stockpiling
- Illegally burning or burying plastic: In accordance with the Air Pollution Act (1987) and Waste Management Act (1996), it is also illegal to burn or bury agricultural plastic.

IFFPG is a not-for-profit organisation funded through two streams of income: a recycling levy charged to producers (70% of income); and a weight-based collection fee charged to farmers (30% of income). The scheme operates as follows:

- Producers must pay a levy to IFFPG for every tonne of farm plastic they supply to the Irish market (failure to do so is illegal). In 2019, the levy stood at €140 per tonne (excl. VAT).
- All silage wrap, sheeting, netting and twine sold legally in Ireland is levied. When farmers purchase levied plastic, they are provided with a 6-digit label code. The code qualifies them for a significant reduction in collection fees.
- IFFPG arranges the collection and recycling of farm plastics across Ireland, either through bookable farmyard collections or a number of local one-day bring-centres (it ran 235 in 2018). Farmers are charged a weight-based collection fee on all the plastic they dispose of; this incentivises a cleaner, less contaminated stream of plastic.
- The majority of plastic is returned via bring-centres (89% of the total tonnage in 2018), likely due to the cheaper collection fees, and the fact that the average farmer is just six miles from their local bring-centre. Farmers can also choose to directly deliver farm plastics to an authorised waste facility, but this is uncommon.

Farm packaging plastics are also used in Ireland (e.g. fertilizer and feed bags and chemical drums). The volumes placed on the market are not currently known, though a rough estimate could be in the region of 3,000 to 4,500 tonnes per year.[319]

[319] Interview with IFFPG, March 2020

Concerning **agricultural plastic packaging** (i.e. fertiliser and feed bags and chemical drums), although not part of the IFFPG EPR scheme as they do not fall under the Farm Plastics Regulations, producers must comply with European packaging regulations and contribute to the cost of managing products' end-of-life. In order to do so, producers pay into the packaging compliance scheme REPAK. IFFPG runs a sister company called Farm Plastic Recycling, which provides a collection service for these plastics, and which is partially funded by a subsidy from REPAK and partially by collection fees charged to farmers. This service is not the only option available for farmers in terms of managing farm packaging plastic waste, but increasing numbers are choosing to use the service.

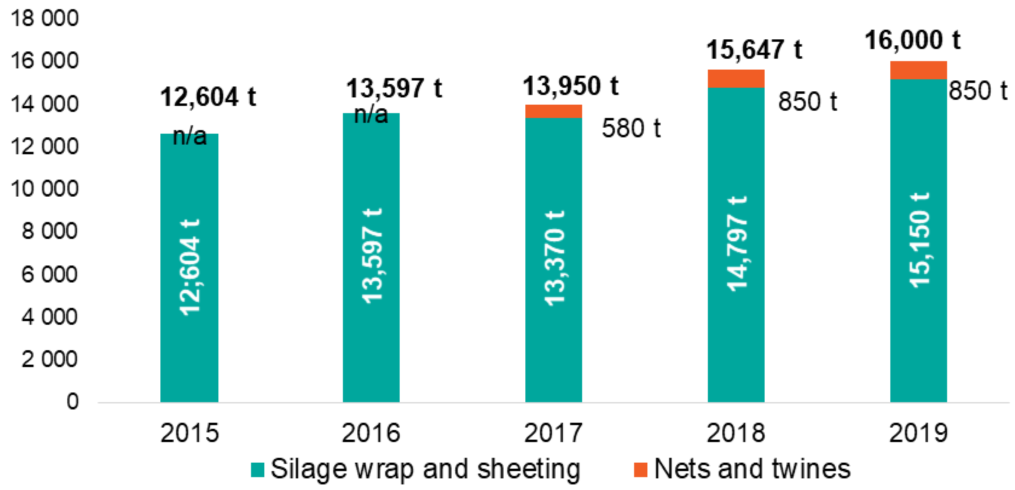
For **agricultural plastic packaging waste,** the collection fees charged to farmers amounts to 5 € per half tonne bag. In 2018, the collection charge was reduced from 10 € to 5 € per half a tonne bag, which stimulated an increase in tonnes collected. The quantity of agri-plastic packaging waste collected in 2017 and 2018 is shown below in Table A2. 12. The increase in the quantity collected can be attributed to the decrease in collection charges.

Table A2. 12: Quantity of agri-plastic packaging waste collected 2017 and 2018 (tonnes)

Year	Large fertilizer & feed bags	Small fertilizer & feed bags	Drums	Total
2017	272 tonnes	245 tonnes	83 tonnes	600 tonnes
2018	310 tonnes	370 tonnes	117 tonnes	797 tonnes

Source: IFFPG

Figure A2. 13: Collection rate of silage wrap and sheeting; and nets and twines and volumes placed on market (in previous year) in Ireland, 2015-2019



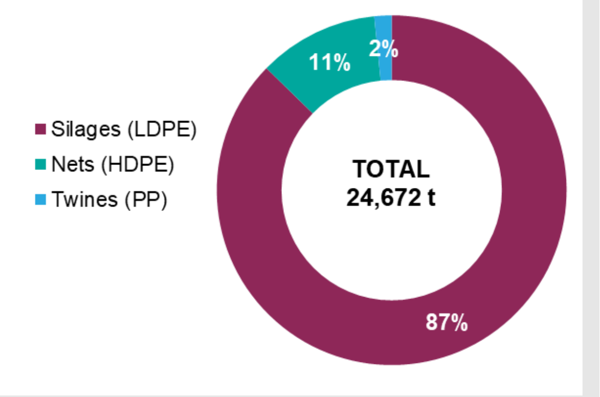
Source: IFFPG

Agri-plastics consumption

Agriculture in Ireland is mostly livestock based. The majority (84%) of agricultural area is devoted to grass (silage, hay and pasture), with the remainder equally devoted to commons and rough grazing, and for production of cereals and other crops.[320] As a result, the main types of agri-plastic applications used are silages (silage wraps and sheeting) and netting and twine used to keep silage bales together (See Figure A2.13). In 2019, the quantity of the main agri-plastic applications placed on the market in Ireland was estimated to be 24,672 tonnes (see Figure A2.14).[321] Silages (wraps and sheeting) represents the main share of the market (87%), followed by nets (11%) and twines (2%).

The amount of silage wrap and sheeting placed on the Irish market has increased in recent years due to the abolition of the milk quota (which limited Irish milk output to 5.5 billion litres per year) and improved grassland management (see Figure A2.15). In comparison, though the volumes of netting placed on the market increased between 2018 and 2019, there is a new product on the market called net replacement film, which some farmers are substituting in for netting. Around 550 tonnes of net replacement film were sold in 2019, and if this trend continues, volumes of netting placed on the market may decline.

Figure A2.14: Market share of specific agri-plastic applications/polymer types in Ireland, 2019



Source: IFFPG

An important feature of silage wrap and sheeting is its durability – in some instances it needs to survive the elements of Irish weather for 12 – 24 months. The use of biodegradable polymers in silage wrap and sheeting is not appropriate, as the plastic may start to lose integrity too early, compromising the quality of silage produced. As it currently stands, IFFPG assumes that for the main types of agricultural plastics, there are no biodegradable alternatives on the Irish market, and that this is not likely to change in the future.

The extent to which **recycled content** is used in agri-plastic applications in Ireland is unknown (if it is used, it is not actively marketed by producers). However, recycled

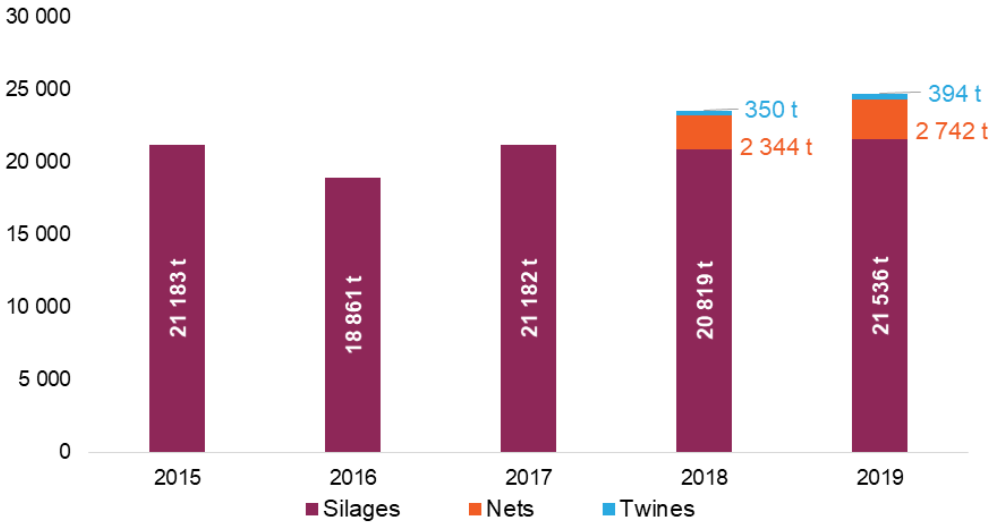
---

[320] Ireland Agriculture and Food Development Authority website on «Agriculture in Ireland». Accessible at: www.teagasc.ie/rural-economy/rural-economy/agri-food-business/agriculture-in-ireland/

[321] Estimated based on data obtained from IFFPG

content is most likely to be present in sheeting, as it has a fairly thick gauge (100 microns) and is not stretched to 200 or 300% like silage wrap.

Figure A2. 15: Quantity of specific agri-plastic applications placed on market in Ireland from 2015-2017 (tonnes)



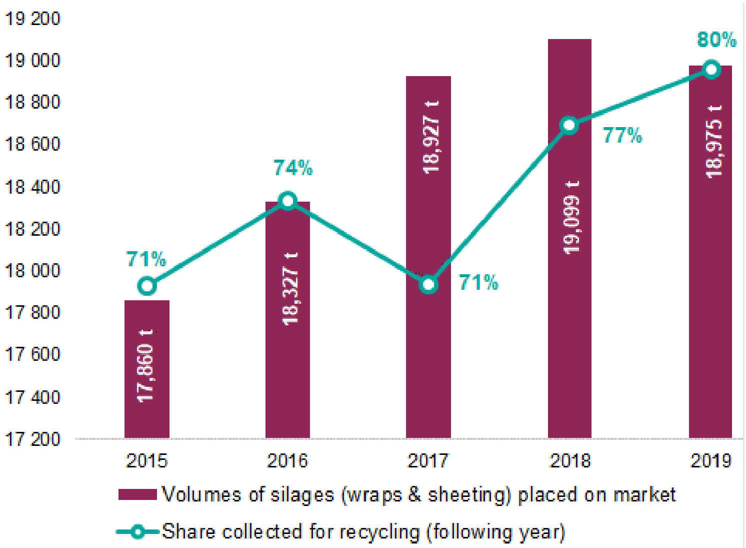
Source: IFFPG

Agri-plastic waste generation and end-of-life practices

Key figures on EOL practices in Ireland are based on data obtained from IFFPG, which cover the main APW streams collected by the scheme: silage wrap, sheeting, nets and twine. These agri-plastic applications are also the main ones placed on the market.

- Data on the total amount of APW generated in Ireland was not available. As such, presents the estimated share of silages (including both silage wraps and sheeting) collected for recycling by IFFPG in relation to the volumes placed on the market (the previous year).
- As reflected in Figure A2. 16, the scheme collects and recycles 70% to 80% of the total volume of silages placed on the market, which largely meets the 70% recycling target set by the

Figure A2. 16: Volume of silages placed on market and share collected for recycling (following year) in Ireland, from 2015 to 2019



Source: IFFPG

Irish government.[322] A key factor influencing the recycling rate include the conditions of the preceding winter period. Under harsh conditions, cattle remain in sheds longer and fodder stocks are depleted (i.e. more silage is used), which produces more plastic waste. This explains for example the 6% increase in the recycling rate between 2017 and 2018. It is estimated that 65-70% of farmers in Ireland use the IFFPG scheme to manage their silage wrap and sheeting at end-of-life.

For **netting and twine,** the amendment to the Farm Plastics Regulations in 2018 required netting and twine producers to contribute to recycling costs for the first time, which stimulated an increase in the quantity collected compared to 2017 (see Figure A2.16).[323] Compared to silage sheets and wraps, the lower recycling rate for nets and twines is due to the lack of sufficient dedicated recycling outlets in Europe. More precise data on how the remaining collected waste is managed is unknown, however, it is assumed that at least a part of it is sent for energy recovery.

Market trends and costs

In regard to waste treatment costs, IFFPG applies two types of costs: a recycling levy charged to producers (70% of income); and a weight based collection fee charged to farmers (30% of income). In 2019, the recycling levy for producers stood at €140 per tonne.

In regard to specific collection costs for netting and twine, in 2017, the additional income from the recycling levy allowed IFFPG to reduce netting and twine collection charges from 15 €/per half tonne sack to 5 €/per half tonne sack.

Trends such as buying fertiliser and feed in bulk (i.e. having a truck deliver enough feed to refill a large on-farm tank) may reduce the size of this market in the future. Other farm plastics like mulch films, common elsewhere in Europe, are rarely used in Ireland. For example, it is estimated that the mulch film market is no bigger than 400 – 500 tonnes per year.[324]

A.2.2.6 Italy

Existing measures and EOL management

The Italian Law Decree 152/2006[325] allows farmers to temporarily store a maximum of 30 m^3 of agricultural waste within the farm's premises for a maximum of one year. After this period, farmers have the following options for EOL management of their APW:

---

[322] Recycling rates allow for a 50% contamination level by weight – mainly moisture – in collected plastics
[323] Book (eISB), electronic I.S. *electronic Irish Statute Book (eISB)*. Accessible at: www.irishstatutebook.ie/eli/2017/si/396/made/en/print
[324] Interview with IFFPG, March 2020
[325] Decreto legislativo 3 aprile 2006, n. 152 Norme in materia ambientale www.bosettiegatti.eu/info/norme/statali/2006_0152.htm

- Use of the municipal collection system e.g. "accordi di programma"[326] and "protocolo di intesa";[327]
- Bring agricultural waste to established collection points; or
- Contract private waste management operators: in some Italian regions, this is the only option available for APW EOL treatment.[328]

In Italy, a dedicated collection scheme was established in 2019 for polyethylene (used to produce greenhouse and mulching films). The scheme is operated by Polieco, the national PRO responsible for the collection and recycling of waste generated by polyethylene-based products. Article 234 of the Law 152/2006 requires producers, importers, users, distributors, recyclers of polyethylene goods to either participate in the Polieco scheme, or to independently organise their waste management e.g. through private waste contractors. A collection scheme also exists for agri-plastic packaging products (e.g. pesticide containers), which is operated by COREPLA/CONAI.

The Italy's Budget Law for 2020 introduced a plastic tax on manufactured products in plastic for single use. The amount of this tax was fixed at 0.45 €/kg and applies to single use plastic items which have the function to contain, protect, manipulate or deliver goods or food. The law excludes from the application of the tax compostable and items produced which recycled plastic. The plastic tax is not yet effective, but it is expected to be from 1 July 2020. This law will not affect all types of agricultural plastic placed in the Italian market but, it may affect some of them such as agrochemical containers, pots, trays and boxes.[329]

Italy included biodegradable mulches in the environmental measures of the two main pillars of European Common Agricultural Policy: Common Organization of the Markets (Pillar I) and the Rural Development Policy (Pillar II) in the Rural Development Plans produced by the Italian Regions. From this EU funding, growers from different regions in Italy get subsidized part of the biodegradable mulching. For example, growers in Emilia Romagna can receive 250 €/ha for the purchase of biodegradable film for fruit and

---

[326] An accordo programma is an agreement between territorial entities (regions, provinces or municipalities) and other public administrations to coordinate their activities.
[327] A protocol di intesa consists of an act of governance stipulated between public and private subjects in agreement with each other to converge on a project. While it is not legally binding, it commits the parties to follow the agreed programme, strategy, procedures, etc.
[328] Agrigoglio (2009) La gestione dei rifiuti in agricoltura n.3/2009 Supplemento special di Agrifoglio n. 31/2009
[329] Link to legislative text accessible at: www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2019-12-30&atto.codiceRedazionale=19G00165&elenco30giorni=true

vegetable crops [330] and grower in Sicily can receive 274€/ha when using biodegradable film for open field fruit and vegetable crops could perceived.[331]

In Italy, producers are required to submit Environmental Compulsory Declarations (MUD) in accordance to Article 189 of Legislative Decree No 152 of 3 April 2006. MUDs contain information on the amounts of waste generated by each business activity, collected, transported and sent to other subjects, as well as waste managed on the national territory, at the level of single European Waste Code (Decision 2000/532/EC). However, some specific producers and sectors, such as agriculture, are not obliged to provide authorities with this declaration. The lack of this obligation affects the completeness of the data reported at National level by ISPRA. Each year, managers of waste treatment plants are required to transmit the information on the quantities of waste managed through MUDs. The data processing of national MUDs provides complete information on the quantities of managed waste at the level of single European Waste Code (EWC).[332] However, it is not possible to identify the economic activity from which waste has been generated. While the quantity of managed waste identified as EWC 020104 in MUDS has almost exclusively agricultural origin, the quantity of managed waste identified by EWC 150102 includes plastic packaging from all types of activities (not only agriculture).[333]

The voluntary scheme for plastic packaging operated by Consorzio C.A.R.P.I. (Consorzio Autonomo Riciclo Plastica Italia) includes producers, waste collectors and recyclers of plastic packing. Some of the recyclers included also recycle agri-plastics (e.g. I.L.A.P SPA). CONAI (Consorzio Nationale Imbalaggi) is the voluntary PRO for all packaging materials that operates through different material-PRO. COREPLA (Consorizio nazionale per la raccolta, il riciclo e il recupero degli emballaggi di Plastica) is the material PRO within CONAI for plastic packaging.[334] CONAI is a non-profit private consortium made of around 900,000 companies (2016). By law, all packaging Producers and Users in Italy have the obligation of adhesion to CONAI.[335] As some packaging products are made of PE, there are some discussions related to who should be the receiver of the eco-fee paid by the

[330] Presentation of Programma di Sviluppo Rurale. Available at: www.fitosanitario.pc.it/files/1515/2059/6280/Presentazione_Province_Rev_CM_09-03-2018_.pdf
[331] Programma di Sviluppo Rurale Mission statement. Available at: www.psrsicilia.it/Allegati/Bandi/Misura10/Disposizioni%20attuative%20definitive.pdf
[332] Decision 2000/532/EC
[333] Based on interview with ISPRA, March 2020
[334] Corepla website. Accessible at: www.corepla.it/conai-dichiarazioni-e-cac
[335] CONAI (2017) Packaging recovery in Italy: The Conai System. Retrieved at: www.conai.org/wp-content/uploads/2014/09/The-CONAI-System_-2017.pdf

producers or users of such goods. [336,337] In these cases, farmers fill specific forms including quantities of agricultural plastic bought and disposed annually. This facilitates the reporting of this type of waste, but as these agreements do not exist for all the Italian provinces, this reporting is not enough to have an exhausting reporting of this type of waste at national level. For example, the Accordo di Programma “Impresa Agricola Pulita” [338] between Abruzzo region and other parties describes the organization of the collection service of agricultural waste in the region and the responsibilities of each party. Article 16 describes the collection scheme for special and non-hazardous waste in which APW is included.

POLIECO has approximately 5000 members.[339] It offers technical, economic and legal advice to its members as well as training activities on environmental protection issues. Membership of the PolieCo Consortium involves a flat-rate payment and an annual contribution for the collection, recycling and re-utilization of polyethylene waste.

Agri-plastics consumption

Limited data is available on agri-plastic consumption, waste generation and associated EOL practices in Italy due to the lack of any specific national legislation or dedicated collection schemes laying down data collection and reporting requirements. As a result, the figures presented in the subsequent sections reflect relevant stakeholder input and available data from the Italian National Institute for Environmental Protection and Research (ISPRA), the Institute for the Promotion of Recycled Plastics (IPPR), and Briassoulis (2013).

Based on assumptions that draw on key findings from Briassoulis (2013)[340] and targeted stakeholder input[341], in 2018, an estimated 176,850 tonnes of agri-plastic applications (excluding packaging) were placed on the Italian market (see Figure A2.17 in appendix). Agricultural films represent 85% (150,850 tonnes) of the total market, which can be further broken down by specific application as follows: mulch films (43,000 tonnes);[342] greenhouses (45,000 tonnes),[343] small tunnels (29,350 tonnes), direct covers (25,000

[336] LCA website, 26 March 2019 “Waste of Polyethylene goods: which consortium has the right to claim the environmental fee?” Accessible at: www.lcalex.it/en/waste-polyethylene-goods-wich-consortium-right-environmental-fee/

[337] Mondaq website, 8 April 2019 “Italy: Waste Of Polyethylene Goods: Which Consortium Has the Right to Claim the Environmental Fee?” Accessible at: www.mondaq.com/italy/Environment/795490/Waste-Of-Polyethylene-Goods-Which-Consortium-Has-The-Right-To-Claim-The-Environmental-Fee

[338] Accordo di Programma “Impresa Agricola Pulita” Mission statement. Available at: www.regione.abruzzo.it/system/files/rifiuti/ORR/impresa-agricola-pulita/Accordo-Programma.pdf

[339] Based on interview with POLIECO Consortium, March 2020

[340] Briassoulis et al. (2013). Review, mapping and analysis of the agricultural plastic waste generation and consolidation in Europe. Waste Manag Res. 2013 Dec; 31(12):1262-78. Doi: 10.1177/0734242X13507968.

[341] Data provided by a large agri-plastics producer in Italy

[342] Information provided by an Italian converter based on the information provided in AMI.

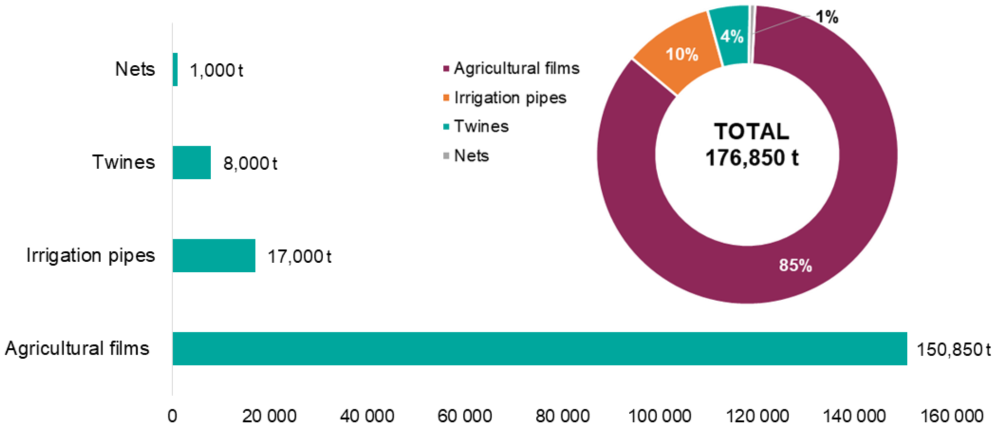
[343] Estimation made by an Italian converter assuming 60,000 ha using greenhouses, between 2 and 2.3 tonnes plastic/ha and an average use of 3 years.

tonnes), and silage films (8,500 tonnes). Irrigation pipes (10%), twines (4%) and nets (1%) are also placed on the market, however at lower quantities.

In 2018, biodegradable mulching film in Italy accounted for about 2,000 tonnes.[344] In regard to the share of virgin versus recycled material, approximately 83% of agri-plastics produced (including packaging) in Italy uses virgin plastic and 17% is made with recycled plastic (see Figure A2. 18).[345, 346] Within the agricultural sector, the use of recycled PE in silage films and irrigation pipes is particularly prevalent.[347]

In regards to specific agri-plastic packaging applications, about 12,700 tonnes of fertiliser sacks and 2,700 tonnes of agrochemical containers were placed on the market in Italy in 2018.[348] According to Novamont, the first major consortium using MATER-BI mulches in Northern Italy was CIO - Consorzio Interregional Ortofrutticoli. In Southern Italy, quantities of biodegradable mulching films in Puglia and Campania are increasing. Approximately 4,000 out of 20,000 hectares of industrial tomato farms in Puglia are now mulched and 30% of mulched surface uses MATER-BI.[349]

Figure A2. 17: Quantity of specific agri-plastic applications placed on market in Italy, 2018 (tonnes)



Source: Own estimations[350]

[344]Assobioplastiche (2019) Crescita costante per l'industria delle bioplastiche anche nel 2018. Available at: www.assobioplastiche.org/assets/documenti/news/news2019/CS_Assobioplastiche%205%20rapporto%205%20giugno%202019.pdf

[345] IPPR - Istituto per la Promozione delle Plastiche da Riciclo (2019). Plastic Application Sectors. Available at: https://plastics4p.it/wp-content/uploads/2019/04/Settori-di-impiego-della-plastica-Andamento-innovazione-per-la-sostenibilita%CC%80-norme-tecniche.pdf

[346] Based on 2018 agricultural plastics production data in Italy (220,000 tonnes, including agri-plastic packaging applications)

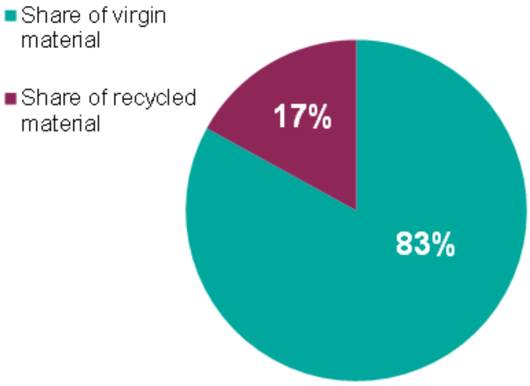
[347] IPPR (2019). Plastic Application Sectors.

[348] Estimated based on Briassoulis et al. (2013) and input provided by an Italian agri-plastics producer.

[349] Novamont website, accessible at: https://agro.novamont.com/page.php?id_page=88

[350] Estimated based on Briassoulis et al. (2013) and input provided by an Italian agri-plastics producer.

Figure A2. 18: Share of virgin and recycled material used in agri-plastic production (incl. packaging) in Italy, 2018



Source: IPPR

Agri-plastic waste generation and end-of-life practices

According to ISPRA, in 2017, 96,809 tonnes of agricultural plastic (excluding packaging) were recycled, 382 tonnes were landfilled and 85 tonnes were incinerated. These amounts represent around 10% of the annual quantity of APW generated in Italy as estimated by Briassoulis (2013).[351] According to Polieco, almost half of the recycled APW are agricultural films, which are mainly represented by recycled greenhouse films (90%) and to a much lesser extent account mulching films (10%).[352] The recycling rate for all APW (including packaging) based on total volume of waste generated in Italy is around 56%.

In 2017, the quantities of waste generated from "agricultural crops and production of animal products, hunting and related services" (Ateco 01), declared in MUD database in were:

- 10,700 tonnes of EWC 020104 (plastic waste – except packaging)[353] and
- 6,438 tonnes of EWC 150102 (plastic packaging).[354]

Market trends and costs

The following collection and treatment costs for agricultural plastic waste were obtained from the Accordo di Programa di Bologna: 300 €/tonne for greenhouse and mulching films; 1,500€/tonne for empty plastic pesticide packaging and 300 €/tonne for boxes.

Participation in the PolieCo scheme involves a flat-rate payment and an annual contribution. The base annual fee may range from € 500 for an association of farmers to

[351] According to Briassoulis (2013), in Italy there is an annual consumption of agricultural films equivalent to 164,000 tonnes (of which 54,675 tonnes of greenhouse films; 46,495 tonnes of mulching films; 29,350 tonnes of small tunnel film; 25,000 tonnes of direct cover film and 8,500 tonnes of silage film).

[352] Based on interview with POLIECO Consortium, March 2020

[353] Based on interview with ISPRA, March 2020

[354] Based on interview with ISPRA, March 2020

€ 15-31 per tonne of polyethylene products.[355] Furthermore, an environmental fee equivalent to about 14 €/tonne is also included in the purchase price of PE films and other PE goods, which is paid by farmers. It is reported however, that this fee is not always paid.[356]

Agri-plastics production

In 2018, Italy produced 220,000 tonnes of agricultural plastics corresponding to an annual turnover of 640 M€. The main products are: LDPE film for greenhouse covers, mulching and silage, irrigation hoses made by HDPE and PVC, and boxes made of HDPE. Most of the annual AP production in Italy used virgin plastic (83%), but some applications also included recycled plastic (17%). The use of recycled PE in silage and irrigation connections is prevalent within the sector. The production trends of greenhouse films have decreased in the last years because farmers are using long-lasting films as well as repair them.[357]

Most of the agri-plastics production in Italy is conventional, however the country also includes one of the international leaders in regard to the manufacturing of biopolymers: Novamont. In 2015, Novamont produced 120,000 tonnes of its biopolymer MATER-BI, which can be transformed using common plastic transformation methods into different plastic products such as mulching film[358], but also biodegradable plastic bags and other items.[359,360] In Italy, there are three converters of MATER-BI polymers into biodegradable mulching film: PATI S.P.A, G.Valota S.p.A and Lirsa Srl.[361] COREPLA/CONAI has a differentiated fees for plastic packaging:[362]

- Sortable/recyclable industrial waste (179 €/tonne)
- Sortable/recyclable household waste (208 €/tonne)
- Non-sortable/ recyclable waste (228 €/tonne)

There are several plastics recyclers in Italy, however most of them only accept industrial plastics and plastic packaging and often reject agricultural plastic waste due to its high content of contamination. Two of the largest AP recyclers in Italy are based in Sicily (I.L.A.P SPA and I.L.P.A.V. SPA). The main producers and recyclers active across the agri-plastics sector in Italy are shown in Figure A2.19.

---

[355] De Lucia & Pazienza (2019) Investigating policy options to reduce plastic waste in agriculture: A pilot study in the south of Italy
[356] Based on interview with POLIECO Consortium, March 2020
[357] IPPR (2019). Plastic Application Sectors.
[358] Mater Bi website, accessible at: http://materbi.com/solutions/agricoltura/telo-per-la-pacciamatura
[359] Novamont (n.d.), Factsheet on Mater-bi polymers. Available at: https://agro.novamont.com/public/Documenti/Factsheet_ITA.pdf
[360] Mater Bi website, accessible at: http://materbi.com/en/solutions/agriculture/mulching-film
[361] Mater Bi website, accessible at: http://materbi.com/partners
[362] IEEP (2017) EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging. Available at: https://ieep.eu/uploads/articles/attachments/95369718-a733-473b-aa6b-153c1341f581/EPR%20and%20plastics%20report%20IEEP%209%20Nov%202017%20final.pdf?v=63677462324

Figure A2.19: Key stakeholders of agri-plastics sector in Italy

A.2.2.7 Spain

Existing measures and EOL management

In Spain, a **voluntary collection scheme** was recently established for the management of non-packaging agri-plastic waste. MAPLA is the association that was specifically created to oversee the scheme, with the overall aim of organising and financing the collection and recovery of non-packaging APW.[363] Promoted by Anaip, Cicloplast and APE Europe along with other founding members, MAPLA currently represents 90% of film converters and distributors in Spain. The scheme will start with the collection of greenhouse and mulching films in Andalusia and eventually expand to national level. An "eco-contribution" will be applied to the purchasing price of all relevant products placed on the market.

Two other collection schemes (SIGFITO[364] and AEVAE[365]) are also in place for agri-plastic packaging waste (e.g. pesticide containers), which is regulated under the Spanish Packaging Law.[366]

Agri-plastics consumption

There are no recent and reliable data on agri-plastic consumption, waste generation and associated EOL practices in Spain. As such, estimations have been made based on relevant available data.

Based on figures reported in Briassoulis (2013)[367] and Cicloplast (2017)[368], it is estimated that on average, approximately 181,970 tonnes of agri-plastic applications (excluding

---

[363] Residuos Profesional website, 11 March 2020. "Sustainable opportunities for the management of agricultural plastic waste". Accessible at: www.residuosprofesional.com/mapla-gestion-residuos-plasticos-agricolas
[364] Sigfito website accessible at: http://sigfito.es
[365] Aeva website accessible at: www.aevae.net
[366] Ley 11/1997, de 24 de abril, de Envases y Residuos de Envases.
[367] Based on 2005 market data
[368] Cicloplast (2017) CIFRAS Y DATOS CLAVE DE LOS PLÁSTICOS Y SU RECICLADO EN ESPAÑA DATOS 2017 www.cicloplast.com/ftp/cifras_datos_clave_plasticos_y_su_reciclado_en_espana.pdf

packaging) are placed on the market in Spain each year (see Figure A2.20 in appendix). Agricultural films (e.g. mulching films, greenhouses and tunnels, silage) account for approximately 53% of the market, followed by irrigation pipes (43%) and twine (4%).

According to Cicloplast, in 2016, an estimated 63% (61,000 tonnes) of agricultural films placed on the market were used for crop production and 37% (35,000 tonnes) for livestock production.[369] Greenhouse films are mainly used for crop production in southern Spain, whereas silage films are more widely used for livestock production in northern Spain (see Figure A2.20).[370]

Approximately 1,500 tonnes of biodegradable mulching film[371] and 500 tonnes of oxo-degradable plastics are consumed annually in the agricultural sector.[372]

Agri-plastics consumption

The consumption of **biodegradable plastic** in Spain is around 1,500 tonnes of biodegradable mulching film.[373] The consumption differs between regions, some regions as Navarra concentrated most of the biodegradable mulching use (20% of the vegetable growers' cooperative in Navarre use biodegradable mulching).

The main conventional AP film converter in Spain (Grupo Armando Alvarez) uses recycled plastic in its production. The application **of recycled plastic within the AP** conversion depends on the application. Plastic mulching can include between 10 and 50% of recycled plastic depending on the thickness of the final product and the quality of the input material. The thicker is the final application, the higher the recycled plastic content can be. For now, the conversion of greenhouse film does not use recycled plastic.

[369] Cicloplast (2017) SITUACION ACTUAL DE LA GESTION DE PLASTICOS AGRICOLAS EN ESPAÑA Y EN EUROPA. https://docplayer.es/81539286-Situacion-actual-de-la-gestion-de-plasticos-agricolas-en-espana-y-en-europa-valsain-2-de-octubre-de-2017.html

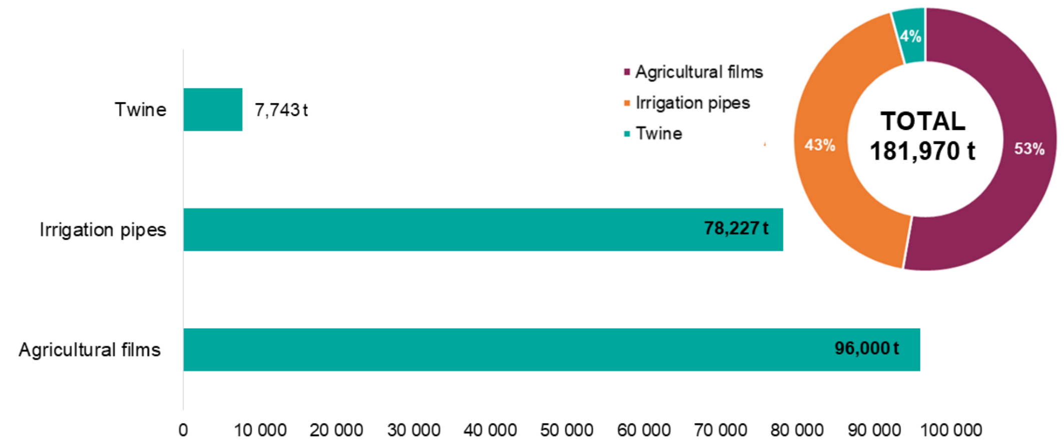
[370] Briassoulis (2013). Review, mapping and analysis of the agricultural plastic waste generation and consolidation in Europe

[371] Based on interview with ASOBIOCOM and a large AP Spanish converter, March 2020

[372] Based on interview with a large AP Spanish converter, March 2020

[373] Based on interview with ASOBIOCOM and a large AP Spanish converter, March 2020

Figure A2.20: Average volume of agri-plastic applications placed on market in Spain (tonnes)



Source: Own estimations[374]

Table A2.13: Spain consumption of AP in total and per region

	Mulching film	Greenhouse covers	Tunnel covers
Total nation-wide	52,857 ha	50,146 ha	14,527 ha
Andalucía	33%	69%	81%
Murcia	26%	10%	
Castilla-La Mancha	19%		
Navarra	10%		
Comunidad Valenciana	7%	4%	12%
Canarias		12%	

Source: Own estimations based on the data reported by Cicloplast (2017)[375]

Agri-plastic waste generation and end-of-life practices

In 2017, approximately 158,857 tonnes of APW (including packaging) was generated in Spain.[376] Almost half of the APW came from irrigation pipes (75,776 tonnes), while the remaining half came from greenhouses and tunnels[377] (23%), silage (11%), mulching (10%), twine (5%), and pesticide containers (3%).

---

[374] Based on data reported from Cicloplast (2017) and Briassoulis (2013)
[375] Cicloplast (2017) SITUACION ACTUAL DE LA GESTION DE PLASTICOS AGRICOLAS EN ESPAÑA Y EN EUROPA. https://docplayer.es/81539286-Situacion-actual-de-la-gestion-de-plasticos-agricolas-en-espana-y-en-europa-valsain-2-de-octubre-de-2017.html
[376] Cicloplast (2017) Key figures and data on plastics and their recycling in Spain, 2017. Retreived from: www.cicloplast.com/ftp/cifras_datos_clave_plasticos_y_su_reciclado_en_espana.pdf
[377] Including large tunnels, small tunnels and direct covers

In regard to EOL practices, 9% (90,608 tonnes) of the plastic recycled annually in Spain comes from the agricultural sector.[378] In the Andalusia region, 39,668 tonnes of APW were recycled in 2016. Most of it came from greenhouse and high tunnels films (59%), followed by mulching films (38%) and other plastics (3%). Based on the APW generated, the recycling rate for APW (including packaging) in Spain is around 57%.

More precise data on the management of APW that is not recycled is not available, however it could be assumed to be treated similar to other types of plastic waste: 2/3 are landfilled and 1/3 incinerated.[379] Other sources indicate that some burning and burial of waste is happening in fields, or left in surrounding areas.[380] For example, ASAJA estimated that in Spain there are “around 950,000 ha of agricultural land and the rural environment that are affected by the contamination by agro-plastics out of use and almost half, need immediate intervention.”[381]

Current APW collection practices in Spain are not homogeneous and the private waste manager who are willing to collect this type of waste are not uniformly spread in the territory either. While in the South of Spain, there are several waste managers able to collect APW, this is not the case for the North of Spain. One of the reasons for this heterogeneity can be the composition of the APW generated in each area. Waste managers are often more interested in the greenhouse films than mulching or silage film, are most of the agriculture using greenhouse films is located in the South of Spain.

This lack of APW collectors in the North of Spain motived the regional administration to either incentivizes the use of biodegradable plastic mulching (e.g. the case of Navarra), while other decided to provide such service to the agriculture through public companies in collaboration with local AG converters (e.g. the case of Cantabria).

MAPLA is a newly formed association that includes 90% of the film converters and distributors of Spain who will act as PRO from 2021. Converters and distributors will pay an “eco-fee” the first time a product is placed into the Spanish market. MAPLA is currently working with authorized APW managers and recyclers to be able to set the scheme and start its operation in 2021. The system will start with the collection of greenhouse and mulching films in Andalusia and its scope will be broaden gradually until collecting at national level and all APW (excluding packaging). The following boxes

---

[378] Cicloplast (2017) CIFRAS Y DATOS CLAVE DE LOS PLÁSTICOS Y SU RECICLADO EN ESPAÑA DATOS 2017 www.cicloplast.com/ftp/cifras_datos_clave_plasticos_y_su_reciclado_en_espana.pdf

[379] In 2017, the amount of recycled plastic overcame the amount of plastic landfilled for the first time, while the amount that is incinerated was half of the recycled. So, 40% of the collected plastic was recycled, 40% landfilled and 20% incinerated (Cicloplast, 2017).

[380] Marí et al. (2019) Economic Evaluation of Biodegradable Plastic Films and Paper Mulches Used in Open-Air Grown Pepper (Capsicum annum L.) Crop. Agronomy 2019, 9(1), 36; https://doi.org/10.3390/agronomy9010036

[381] http://www.innovationatiris.com/2020/02/21/iris-invites-you-to-the-ap-waste-project-presentation-on-18th-march/

describe the schemes used in the Spanish regions of Andalusia, Navarra and Catalonia, including key success factors and existing obstacles.

In regard to recycling trends and practices, greenhouse and tunnel films are often collected clean (15-20% **soil contamination rate**) and its recycling is simple, while mulching film has higher contamination rates (40-60%) and its recycling process is more complex. On the other side, greenhouse and tunnels films are used longer times than mulching (3-4 years instead of the annual life of the mulch) and the longer the use, the more degraded is the material when it is collected. The degradation of the collected waste material affects the quality of the recycled material. Low quality recycled PE can be used for applications made by injection, while high quality recycled PE can be used also for blown moulding.

Box A2.3: Collection scheme in Andalusia region, Spain

Overview of collection scheme in Andalusia Region, Spain

Due to the large amount of APW generated in **Andalusia**, this Spanish region established Extended Producer Responsibility requirements for APW through Decree 73/2012, Article 99 and Article 100. Participation in the EPR scheme is mandatory for converters and distributors placing agri-plastic products on the market in Andalusia.

CICLOAGRO was authorised by Junta de Andalusia in 2012 as the PRO for agricultural plastic waste to collectively respond to the individual obligations of the agricultural plastic producers established in the Decree 73/2012.

The CICLOAGRO system applied only to APW placed on the market in Andalusia. The main income of the system stem from the sales of recovered materials. Participating farmers and recyclers agree on collection costs, however sales of recovered materials are highly dependent on the market of virgin plastic.

In March 2018, CICLOAGRO's ceased to operate due to lack of regional competences. Although there is some controversy around this, in Spain, regions cannot regulate Extended Producer Responsibility schemes for waste fractions that are not regulated at National level first.[382]

Success factors

- Through the CICLOAGRO scheme, recycling of APW in Andalusia grew from a few tonnes (in 2012) to almost 49,700 tonnes in 2016, reaching a collection rate of 80.5%.[383]
- In Andalusia, the greenhouse plastic waste generation is larger than the mulching waste generation. This combination incentivised recyclers to increase collection and

[382] Europa Press website, 19 April 2018 "Cicloagro ceases its activity as a collective management system for agricultural plastics in Andalusia. Accessible at: www.europapress.es/andalucia/noticia-cicloagro-cesa-actividad-sistema-colectivo-gestion-plasticos-agricolas-andalucia-20180419161643.html

[383] APE EUROPE, 16 February 2017. Board meeting, Frankfurt. Retreieved from: www.plastiques-agricoles.com/wp-content/uploads/2017/05/MinutesBoardmeeting20170216.pdf

- recycling of APW. With the market prices of the period 2012-2018, the high value of greenhouse plastic waste (150-200 €/tonne) compensated the negative price of mulching film (-5 -0 €/tonne).
- The Andalusia law and CICLOAGRO initiative incentivised the creation of a good network of recyclers in the region.

Obstacles

- The economic viability of the scheme depended largely on the oil price. There was not a fix income to sustain the system when prices of the virgin material dropped. AP converters and distributors were not paying for the end-of-life management of their product.
- An EPR within a region could motivate its farmers to purchase APs in the surrounding regions (without EPR schemes in place).
- Farmers sometimes sold their high value plastic to non-authorized managers who offered higher prices, reducing the income of the scheme.
- Farmers in the CICLOAGRO scheme were not paid neither charged by the system, and there were no incentives to reduce impurities. This implied higher collection costs, because plastic was being transported with a lot of soil attached, as well as treatment and disposal costs.
- While farmers were mandated to collect their APW, there was no control of compliance, so in some cases the collection of the mulching was not done properly.

Box A2.4: Collection scheme in Navarra region, Spain

Overview of collection scheme in Navarra

Navarra region generates 2,692 tonnes of APW annually (44% mulching plastic, 10% greenhouse film, 5% tunnel films, 14% silage film and 27% other), 65% of which is collected. 11% of the collected APW is recycled and the rest is landfilled in *El Culebrete*. Farmers are responsible of collecting and bringing their APW directly to the landfill. Farmers are charged: 36 €/tonne for the management of the waste and 20 €/tonne as landfill tax.

According to Novamont, 80% of the tomatoes production in Navarra uses biodegradable film. The reason for that is that most of the arable land used for growing tomatoes is rented and has to be returned clean to the landlord.[384]

Cooperativas Agro-alimentarias de Navarra (UCAN) acts as representative of farmers and farmers' cooperatives in the region and carries out three main initiatives related to agri-plastics:

- Campaigns to raise farmer's awareness on agri-plastics use and end-of-life management. They published a guide for farmers advising to use one type of mulching film (conventional or biodegradable) per type of crop. Biodegradable mulching is only recommended for tomatoes cultivation and it is considered uneconomic or unusable

[384] Novamont website on "biodegradable mulching films". Accessible at: https://agro.novamont.com/page.php?id_page=88

for other types of vegetable grown in the region.[385] The guide also suggests to re-use conventional mulching film for asparagus.

- Lobby the regional government to provide financial support to the farmers using biodegradable mulching film to compensate for the extra production costs related to the use of biodegradable plastic in comparison to conventional films. They estimated that using biodegradable mulching films implies 37% higher production cost for the farmers (even assuming a 20% contamination of APW and 18 h/ha to remove the conventional APW from the fields). In the region, purchasing biodegradable mulching film costs 4 times more than conventional mulching films.
- After China's importation ban, most of the APW collected in the region is landfilled because of the lack of recycling options for low quantity and quality APW (mainly mulching) produced in the region. UCAN is working with local recyclers interested in converting such waste stream into valuable products (e.g. outdoor furniture).

Success:

- The agro-food cooperatives of the region are already using 20% of biodegradable agri-plastics.
- The region has previously subsidised the use of biodegradable plastic and this measure contributed to increase bio-AP consumption.
- UCAN has identified which crops and techniques should use biodegradable plastics and which ones should keep on working with conventional AP.

Obstacles:

- Plastics producers are not currently involved in the initiatives because the national legal framework does not establish the EPR of this type of waste.
- Farmers using bio-AP are overall satisfied with the performance of bio-AP. However, there are some farmers who are reticent to use them because of the price, sometimes (too early) degradation, perforation of the film by weeds and more complex handling.

Box A2.5: Collection scheme in Catalonia, Spain

Overview of collection scheme in Catalonia

In Catalonia there are some collection schemes for greenhouse films and livestock silage.

Greenhouse film: In 2002 the Catalan Waste Agency, the City Council of Vilassar de Mar, the Supra-municipal entity "Mancomunitat de l'Alt Maresme per a la gestió de residus sòlids urbans I del medi ambient"and the agricultural cooperative "Cooperativa Agraria Santboiana" signed an agreement to implement a waste management system for plastics used in agriculture to promote its recycling and valorisation. This agreement allowed the creation of 3 collection centres equipped with a press and storage space. The centres could give services to all APW holders regardless of the geographical origin.

[385] UGAN (2019) Good practices Manuel for management of plastics in the Agricultural sector. Retreived from: http://ucan.es/wp-content/uploads/2019/09/MANUAL-BUENAS-PRA%CC%81CTICAS-GESTION-PLASTICOS-AGRARIOS.pdf

At the end of 2018, one of the collection centres experienced problems to find a waste manager willing to collect their bales. Contrary, the other two collection centres located in another municipality did not experienced such problem (at least by that time) and their bales were properly collected and managed by an authorized waste manager.

Livestock silage: In some rural areas, there used to be a problem with the management of livestock silage, which was often left in the fields and surrounding areas. To solve this situation, three Catalan Consell Comarcals (Local Authorities) reached voluntary agreements with farmers to collect and manage Agriculture Plastic Waste and farmers pay the cost of the service. One of them applies a fix fee per farm and the two others charge the farmers based on the volume of APW. The silage film recovered by them was mostly sent to China until the importation ban. This plastic is currently used as Solid Derived Fuel or landfilled.

Regarding biodegradable mulching film, the University of Lleida has carried out a project to demonstrate the application and benefits of using biodegradable mulching films in Catalonia[386]. Some Catalan farmers and cooperatives, such as Cal Valls, Petit Pla and l'Hort de Cal Castell are already using them.[387]

Success factors

- Agriplastics are being collected and farmers pay for the cost of the service.

Obstacles

- The producers are not being responsible for end-of-life of their products. Public authorities need to take care of it to avoid environmental problems.

Market trends and costs

As reflected in Table A2.14, market prices for bio-degradable plastics remain high in Spain and can cost up to 2-4 times more compared to conventional plastics.[388,389] Collection costs for mulching films are estimated to range between €10 and 20/tonne. The market value of collected greenhouse film waste (for recycling) is about €100-150/tonne.[390]

Table A2.14: Market prices in Spain for agri-plastic materials

Type of plastic	Main polymers used	Price (€/ha)
Conventional	Low-density PE	404 €/ha

[386] University of Lleida (2019) Viability of the use of biodegradable mulching films in Catalan horticultural sector. Retreived from: https://ruralcat.gencat.cat/documents/20181/4633934/19_Demostraci%C3%B3+de+la+viabilitat+de+l%27%C3%BAs+dels+encoixinats_UdL_FITXA+INICIAL+DEMOS.pdf/76df34d6-d065-4bb0-b351-7e703844de81

[387] Novamont website Accessible at: https://agro.novamont.com/

[388] Mari et al. (2019). Economic Evaluation of Biodegradable Plastic Films and Paper Mulches Used in Open-Air Grown Pepper (Capsicum annum L.) Crop.

[389] Based on interview with a Spanish AP film converter and growers' representatives, March 2020

[390] Based on interview with Spanish Recycler of agri-plastic waste, April 2020

Type of plastic	Main polymers used	Price (€/ha)
Biodegradable (Mater-Bi®)	Polycaprolactone, starch blend	1164 €/ha
Biodegradable (Sphere®)	Potato starch, recycled polymers	772 €/ha
	Polylactic acid, co-polyester	931 €/ha
Biodegradable (Ecovio®)	Polylactic acid, polybutylene adipate terephthalate, starch	505 €/ha

Source: Mari (2019); estimates provided by Spanish producer of agricultural plastics

Agri-plastics production

Spain is one of the largest producers of agri-plastics in Europe. Grupo Armando Alvarez leads the European market, which is composed of approximately 25 international companies.[391] On average, the company produces around 120,000 tonnes of conventional agri-plastic film, 1,500 tonnes of biodegradable agri-plastic film and less than 500 tonnes of oxo-degradable agri-plastic film. [392] The main producers and recyclers active across the agri-plastics sector in Spain are shown in Figure A2. 21.

Figure A2. 21: Key stakeholders of agri-plastics sector in Spain

A.2.2.8 Sweden

Existing measures and EOL management

In Sweden, the management of agri-plastic waste is based on voluntary producer responsibility. SvepRetur is the non-profit industry association responsible for collecting agri-plastic waste and reports annually to the Swedish Environmental Protection Agency (SEPA).[393] Almost all the agricultural market players in Sweden are involved in the SvepRetur system.

The Swedish Environmental Protection Agency (SEPA) is working for sustainable plastic use in general, not specific for agriculture sector. The SEPA also promotes research and development projects and supports business education to stimulate sustainable

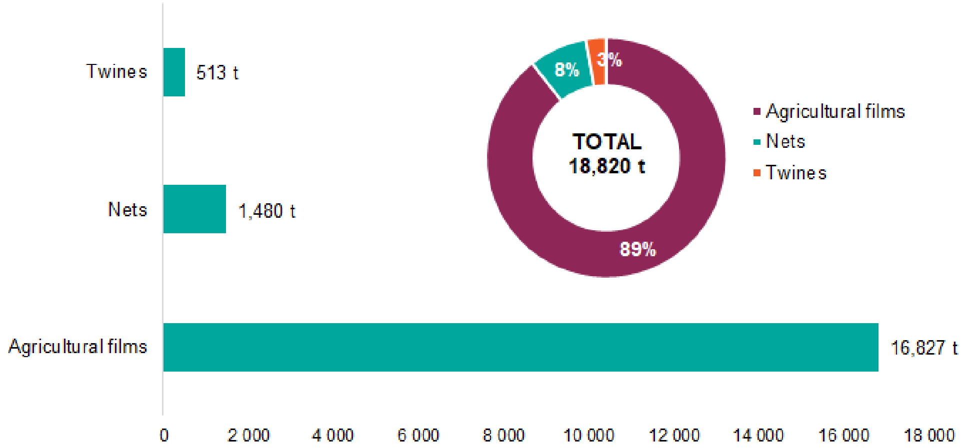
[391] Based on interview with a Spanish conventional AP film converter, March 2020
[392] Based on interview with a Spanish conventional AP film converter, March 2020
[393] SvepRetur website, accessible at: http://svepretur.se/

innovation and use of new bio-based materials. For example, a report was published in 2019 on major plastic streams in Sweden and giving facts and practical advice about plastics. SEPA also stimulates sustainable innovations by creating dialogues between demand and supply, initiate purchaser groups to demand and specify requirements, funding project by investment grants, funding work with standardization and competitions based on challenges. The SEPA supports the standardization of packaging to the Swedish Standard Institute by establishing an ISO secretariat to develop a global standard for plastic recycling.

Agri-plastics consumption

In 2019, approximately 18,820 tonnes of agri-plastic applications (excluding packaging) were placed on the market in Sweden (see Figure A2.22).[394] Agricultural films e.g. stretch films and silages (tubes and sheets) used in livestock production accounted for about 72% (16,827 tonnes) of the market, followed by nets (1,480 tonnes; 8%) and twines (513 tonnes; 3%).

Figure A2.22: Quantity of agri-plastic applications (excl. packaging) placed on market in Sweden, 2019 (tonnes)



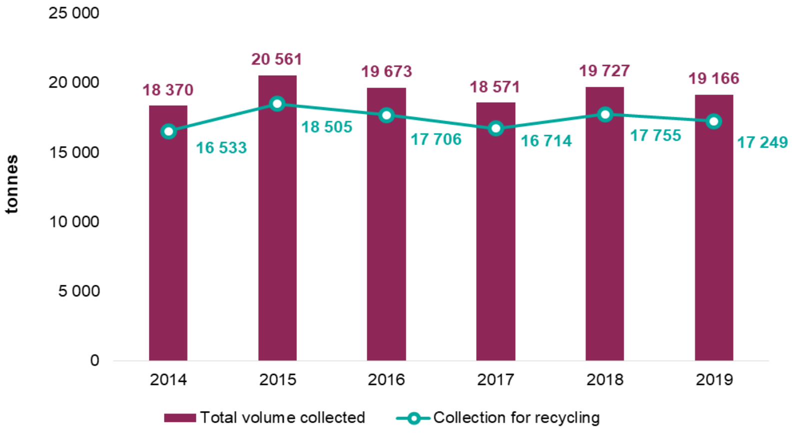
Source: Svepretur/SEPA

[394] Based on questionnaire responses submitted by the Swedish EPA/SvepRetur

Agri-plastic waste generation and end-of-life practices

Figures on the total amount of APW generated in Sweden are not available. Nevertheless, data on EOL practices reported by SvepRetur indicate that most of the APW generated in Sweden is collected and sent for recycling. The rest of the waste that cannot be recycled e.g. highly contaminated products are incinerated or used for energy recovery.

Figure A2.23: Estimated volume of APW collected and recycled (incl. packaging) in Sweden from 2014 to 2019 (tonnes)



Source: SvepRetur/SEPA

Data on EOL practices are based on the total amount of APW collected by SvepRetur. In 2018, SvepRetur estimates that almost 92.5% of the total agri-plastics (including packaging) put on the Swedish market (19,194 tonnes) was collected.

Of the total amount collected, 88% (16,891 tonnes) was recycled, while 12% was sent to energy recovery.[395] The share of agri-plastics collected each year in Sweden has remained relatively stable since 2014 with an annual average collection rate of 93% and recycling rate of 90% (out of amount collected) (Figure A2.23). It should however be noted that according to SvepRetur, it is difficult to accurately estimate recycling rates due to high contamination and imports.[396] Most of the collected plastics are agricultural films, however the share of specific applications is not known. Nonetheless, considering the high percentage of recycling, it can be assumed that the majority of products are based on PE (agricultural films) and PP (nets).

Kretslopp & Recycling i Sverige AB (KRSAB)[397], a collection company and recycler, assigned by SvepRetur to collect the plastic directly from the farm or at collection points. The entire recycling process for agricultural plastics is financed through a charge corresponding to the actual cost incurred. The charge is paid directly on agri-plastics purchase price. The agri-plastic waste are collected and treated by specialised facilities in Sweden. The main treatment process used is mechanical cleaning and the production of recycled pellets. Only a marginal share of the agri-plastics collected is sent to third countries for recycling. The small part of the waste that cannot be recycled e.g. highly

---

[395] Based on questionnaire responses submitted by the Swedish EPA/SvepRetur
[396] Based on questionnaire responses submitted by the Swedish EPA/SvepRetur
[397] KRSAB website, accessible at: http://krsab.nu/

contaminated plastic containers is incinerated or used for energy recovery. Farmers are encouraged to re-use products when it is possible (e.g. non-woven material and silage sheets). They have guidelines on how to deliver, pack, clean material when leaving it to SvepRetur collection points. The plastics collected should be as dry and clean as possible and each type of plastics is placed separately. Agri-plastics have different forms and must be sorted to be recycled. The plastic is sorted into six categories by SvepRetur:

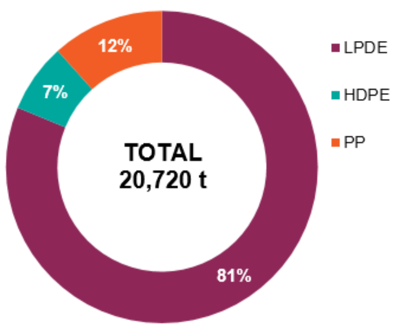
- Silage stretch film
- Mantle foil
- Bale nets and PP-yarns from bales
- Foil (silage bags, silage into foils, silage tubes, cultivation foil)
- Non-woven plastics (fibre cloth)
- Big bags
- Bobbins and cores from silage stretch film, foil and nets
- Plastic containers

Share of biodegradable polymers

Biodegradable plastics are not used very much in Sweden. The main type of polymers used in Sweden is LPDE (81%) followed by PP (12%) and HDPE (7%) (Figure A2.24). Moreover, Svepretur, Swedish agri-plastics waste collector, only collects materials that can be recycled like PE or PP, not biodegradable plastics. Considering the high percentage of recycling, SEPA suggests that the majority of the products are based on PE and PP as follows:

- LLDPE, Big bags with inner sack (packaging)
- LDPE, Black and white and thin crop film (agri-plastic films)
- PP nets and rope
- PP fiberduk, PP Non-woven
- Pipes of different plastic materials

Figure A2.24: Share of main polymers used in agri-plastic products in Sweden

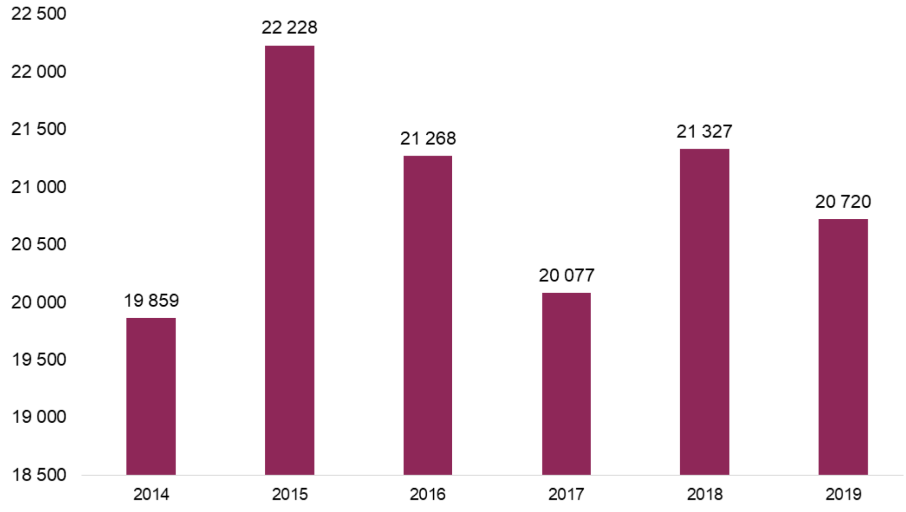


Source: Svepretur

Share of recycled content

The extent to which recycled content is used in agri-plastics in Sweden is unknown. However, the agri-plastics sector has set a target that at least 30% of agriculture plastics placed on the market should be recycled.

Figure A2.25: Quantity of agri-plastics (incl. packaging) placed on the market in Sweden from 2014 to 2019 (tonnes)



Source: Svepretur

A.2.2.9 Other Member States

Reliable and recent data on agri-plastics and their end-of-life management is not available for Bulgaria, the Netherlands and Poland. As such, this section summarises some of the key relevant findings in relation to general waste management identified in existing literature and where applicable, through stakeholder input.

Bulgaria

In Bulgaria, greenhouses are among the main agri-plastic applications used. In 2010, 1,028 hectares of the 43,191 hectares used for crop production were covered by greenhouses (53% polyethylene greenhouses and 47% glass greenhouses).[403]

The majority of the agri-plastic waste generated in Bulgaria is landfilled. There is no national or local collection scheme, nor landfilling restrictions specific to APW. In 2016, the overall plastics recycling rate was estimated to be around 20% (plastics packaging recycling rate around 22.5%) and energy recovery 5%.[398] However, for agricultural plastics specifically, Bulgaria is reported to have one of the lowest rates of recycling in

[398] PlasticsEurope (2018). Plastics – the Facts 2018. Available at: www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

the EU.[399] Private companies, however are emerging in the country to collect and recycle used plastics.[400]

The Netherlands

In the Netherlands, the main agri-plastic applications used are greenhouses and large tunnels (around 400 hectares covered in 2012) and direct covers (1,300 hectares covered in 2012)[401] for crop production e.g. flowers and mushrooms.

Landfill restrictions are implemented in the Netherlands. The majority of agri-plastic waste is sent to incineration for energy recovery.[402] In 2016, the energy recovery rate was 65% and 35% for the rate of recycling for all plastic waste.[403]

In accordance with the Dutch Waste Management Contribution Agreement (ABBO), EU Packaging legislation (Directive 94/62/EC) and extended producer responsibility principles, producers and importers are responsible for the EOL management of the plastic packaging products put on the Dutch market. The 2013 Packaging Framework Agreement (Raamovereenkomst Verpakkingen) establishes recycling targets.[404] In 2016, the Netherlands had one of the highest plastic packaging recycling rates (more than 45%) in the EU.[403]

There are several plastic recycling plants in the Netherlands. For example, Daly Plastics, produces recycled plastic granulates from agricultural films for the manufacturing of new products. Around 64,000 metric tons of used agricultural films are recycled into reusable polyethylene per year at their Zutphen site.[405]

Poland

In Poland, the Polish Waste Act establishes the responsibility of farmers for the management of their waste.[406] Further, in accordance with Polish national law, municipalities are responsible for the collection and management of municipal waste. However, agri-plastics are not specifically covered within national legislation, which has led some municipalities to not collect APW. In some areas, localised collection systems

---

[399] European Commission (2018). A European Strategy for Plastics in a circular economy. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0016&from=RO

[400] Integra Plastics Website: https://integra-plastics.com/integra-plastics.php

[401] Scarascia et al. (2012). Plastic materials in European agriculture: actual use and perspectives.

[402] PlasticsEurope (2018). Plastics – the Facts 2018. Available at: www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

[403] PlasticsEurope (2018). Plastics – the Facts 2018. Available at: www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

[404] Afvalfonds, Legislative framework. Available at: https://afvalfondsverpakkingen.nl/en/legislative-framework

[405] Recycling today (2019). Daly Plastics recovers agricultural and packaging film. Available at : https://www.recyclingtoday.com/article/daly-plastics-recovers-agricultural-and-packaging-film/

[406] Agroberichtenbuitenland (2020). Poland: Problems with the utilization of agricultural films. Available at : https://www.agroberichtenbuitenland.nl/actueel/nieuws/2020/01/21/problems-with-the-utilization-of-agricultural-film

for agri-plastic waste (used mulching films, greenhouses, etc.) have been organised, however no collection scheme is established at regional or national level.

Most of the plastic waste is landfilled, which is not prohibited in Poland.[407] Efforts are being made to further improve APW management as reflected in the initiative "Removal of agricultural films and other waste from agricultural activities", launched in 2019 by the National Fund for Environmental Protection and Water Management to support the collection of agri-plastics waste.[408]

A.2.3 Non – EU Country Level Analysis

A.2.3.1 Canada

Canada has a combination of both voluntary and mandatory collection schemes for the management of agri-plastic waste. The collection scheme for agricultural plastic film waste is operated on a voluntary basis by CleanFarms, however only in selected provinces (see Table A2.15).[409]

In Canada, agri-plastic applications placed on the market e.g. agricultural films (silage films, bale wraps and twine), grain and seed transportation bags, and fertiliser and pesticide packaging are principally used for livestock production. Data was not available in regard to the volumes of specific agri-plastic applications placed on the market. As such, consumption estimates can be assumed to be more or less aligned with CleanFarms estimates on the amount of APW generated in Canada.[410]

On average, approximately 45,000 tonnes of (non-packaging) APW is generated annually in Canada.[411] Of this amount, only about 5% (2,250 tonnes) is recycled, 9% (4,050 tonnes) is collected for diversion (i.e. diverted from direct disposal and sent to a sorting facility), 4% (2,000 tonnes) is incinerated (waste-to-energy), and 82% (36,700 tonnes) is landfilled (Figure A2.26). The value recovery rate of is estimated to be 10%.

---

[407] Borkowski, Kazimierz (2016) Plastics Recycling and Energy Recovery Activities in Poland – Current Status and Development Prospects. Retrieved from: www.vivis.de/wp-content/uploads/WM6/2016_WM_375-388_Borkowski.pdf

[408] http://nfosigw.gov.pl/oferta-finansowania/srodki-krajowe/programy-priorytetowe/usuwanie-folii-rolniczych/

[409] Recycling Product News website, 25 October 2019 "Cleanfarms has agri-plastic waste in the bag: Non-profit environmental stewardship is helping Canadian farmers keep their operations clean and sustainable by managing agriculture industry plastic waste" Accessible at: www.recyclingproductnews.com/article/32240/cleanfarms-has-ag-plastic-waste-in-the-bag

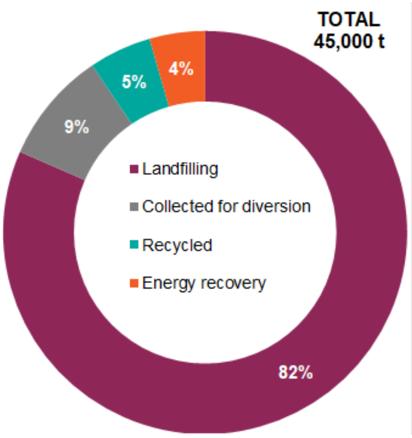
[410] Canadian Minstry of Environment (2019) Economic study of the Canadian plastic indsutry, markets and waste. Retreived from: www.taxpayer.com/media/En4-366-1-2019-eng.pdf

[411] Canadian Minstry of Environment (2019) Economic study of the Canadian plastic indsutry, markets and waste. Retreived from: www.taxpayer.com/media/En4-366-1-2019-eng.pdf

Since their establishment, the EPR schemes in Canada have broadened their scope and geographical area of coverage. The first type of agri-plastic waste collected was empty pesticides/fertilizers containers (up to 23 litters). The collection of EOL pesticides/fertilizers containers started more than 30 years ago as a voluntary EPR scheme in Alberta.[412] In addition, a dedicated collection and recycling programme for end-of-life grain bags also exist in the province of Saskatchewan (Box A2.6).

Cleanfarms is the only large-scale non-profit industry stewardship organisation that operates the collection and recycling of agri-plastic waste in Canada.[413] Cleanfarms operates mostly on a voluntary basis, but also within 3 province-regulated programs: Saskatchewan (for the collection of grain bags) and Manitoba and Quebec (for the collection of empty containers).[414] In 2018, around 65% of small containers placed on the market were collected through the Cleanfarms scheme.[415]

Figure A2.26: EOL treatment of APW (excl. packaging) in Canada (annual average)



Source: Canadian Ministry of Environment

Table A2.15: Overview of APW collection schemes operated by Cleanfarms in Canada, 2020[416]

Provinces	Bags & large tote bags	Containers up to 23L	Grain bags	Totes & drums	Twine, bale wrap & silage film	Unwanted Pesticides & animal medications
British Columbia		X				X
Alberta		X	X	x	X (only twine)	X
Saskatchewan		X	X	x		x

[412] Recycling Product News website, 25 October 2019 "Cleanfarms has agri-plastic waste in the bag: Non-profit environmental stewardship is helping Canadian farmers keep their operations clean and sustainable by managing agriculture industry plastic waste" Accessible at: www.recyclingproductnews.com/article/32240/cleanfarms-has-ag-plastic-waste-in-the-bag

[413] Recycling Product News website, 25 October 2019 "Cleanfarms has agri-plastic waste in the bag: Non-profit environmental stewardship is helping Canadian farmers keep their operations clean and sustainable by managing agriculture industry plastic waste" Accessible at: www.recyclingproductnews.com/article/32240/cleanfarms-has-ag-plastic-waste-in-the-bag

[414] CleanFarms website, accessible at: https://cleanfarms.ca/programs-at-a-glance/

[415] CleanFarms (2018) Annual report. Retrieved at: https://cleanfarms.ca/wp-content/uploads/2019/04/Cleanfarms-2018-Annual-Report-EN.pdf

[416] CleanFarms website, accessible at: https://cleanfarms.ca/programs-at-a-glance/#top

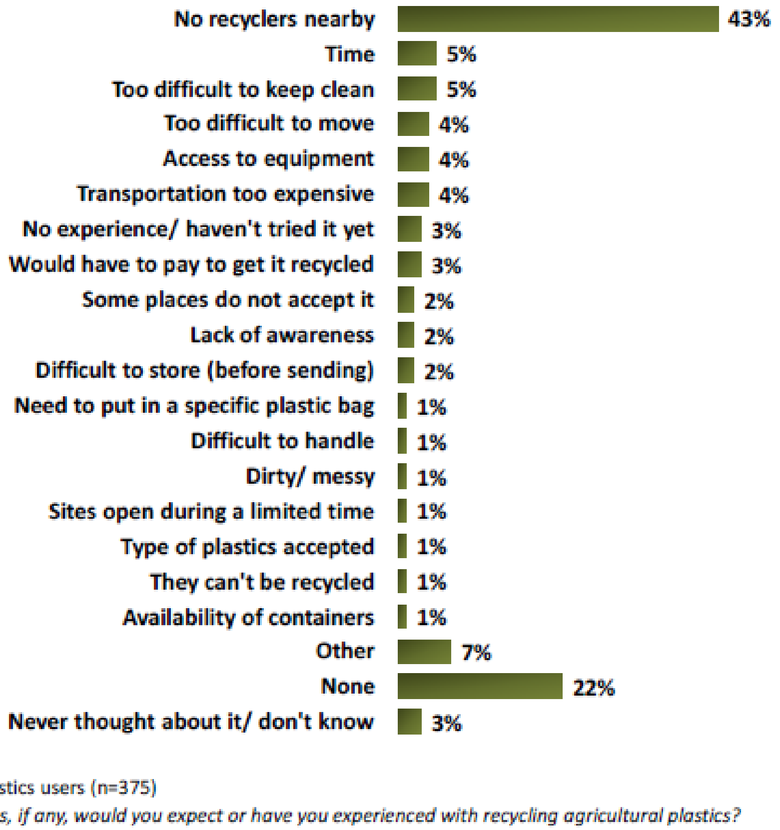
Provinces	Bags & large tote bags	Containers up to 23L	Grain bags	Totes & drums	Twine, bale wrap & silage film	Unwanted Pesticides & animal medications
Manitoba	x	X	x	X	X	x
Ontario	X	X		X		x
Quebec	X	X		X		x
New Brunswick	X	X		X		x
Nova Scotia	X	X		X		x
Prince Edward Island	X	X		X		x
Newfoundland		X		X		X

Box A2.6: Collection and recycling programme for grain bags in Saskatchewan

In 2016, the province Saskatchewan passed The Agricultural Packaging Product Waste Stewardship Regulations[417], which regulate agricultural grain bags collection. With the regulation in place, financial responsibility for the recycling program transfers from public funding to industry. A non-refundable Environmental Handling Fee (EHF) came into effect on November 1st, 2018. The EHF is used to cover the cost of collecting the bags at designated collection sites and transporting them to end markets for recycling into new products such as garbage bags. The non-refundable EHF equals 25 cents per kilogram, which is added to the price of the bag when purchased (a bag that is approximately 125 kg).[418]

[417] Agricultural Packaging Product Waste Stewardship Regulations (2016) Retrieved at: www.publications.gov.sk.ca/freelaw/documents/English/Regulations/Regulations/E10-22R4.pdf
[418] https://cleanfarms.ca/wp-content/uploads/2019/04/Cleanfarms-2018-Annual-Report-EN.pdf

Figure A2.27: Difficulties identified by farmers from Alberta with regards to recycling agri-plastics



Source: Alberta Government (2012)[419]

A.2.3.2 Iceland

The agricultural sector in Ireland is largely dominated by livestock production (approximately 75%) based on forage grazing and silage production.[420] According to the Icelandic Recycling Fund (IRF), around 1,800 tonnes of agricultural films (silage) are placed annually on the market in Iceland.[421] This figure also corresponds to the 1,600 tonnes of agricultural films sold in 2019, reported by APE Europe.[422]

In Iceland, a mandatory EPR scheme for silage films has been established since 2003. It is

---

[419] Alberta Government (2012). Agricultural Plastics Recycling Survey. Final Report October 2012. www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/com14387/$file/Plastics_Recycling_Agricultural_Producers_Survey_Final_Report.pdf?OpenElement

[420] OECD (2008). Environmental Performance of Agriculture in OECD countries since 1990. Available at: www.oecd.org/iceland/40801889.pdf

[421] Based on interview with IRF, March 2020

[422] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics

operated by the Icelandic Recycling Fund (IRF), a state-owned PRO.[423] A recycling fee is charged to producers and importers of silage films based on the cost of waste management and treatment operations e.g. collection, transportation, recovery and recycling. The recycling fee is included in the price of silage films at the point of purchase; therefore the collection system is also in part funded by the farmer. In 2020, the fee was 28 Kr/kg (equivalent to 0.19€/kg).[424] In addition to dedicated collection points, used silage films are also directly collected from farms at least twice a year.[425]

In 2020, the collection rate for silage film is estimated to be around 90% (with an estimated contamination rate of around 30%).[426] Pure North Recycling, the main plastics recycler in Iceland, recycles the collected silage film waste to produce plastic flakes, which are then sold to other European countries to manufacture plastic products.[427,428]

A.2.3.3 Norway

The agriculture sector in Norway is mostly devoted to livestock production e.g. forage and grain production.[429] In regard to specific agri-plastic applications, APE Europe estimates that in 2019, 8,800 tonnes of agricultural films were placed on the market in Norway.[430] Data on the quantity of other specific agri-plastic applications placed on the market in Norway was not available.

Since 1997, a dedicated voluntary EPR scheme for agri-plastic packaging e.g. fertiliser and seed bags and agricultural films e.g. silage films has been overseen by Grønt Punkt Norge (GPN).[431]

In 2018, 17,866 tonnes of APW (including packaging) was collected by the GPN scheme. Of the amount of APW collected, 10,719 tonnes was recycled.[432] According to GPN, the quantity collected for recycling reflects about 83.5% of the total share of agri-plastic

---

[423] UN National reports on waste management (sense data): Iceland Retrieved at: www.un.org/esa/dsd/dsd_aofw_ni/ni_pdfs/NationalReports/iceland/waste.pdf
[424] www.step-info.org/iceland-waste-products-recycling-fees-act-no-162-2002.html

[425] UN National reports on waste management (sense data): Iceland Retrieved at: www.un.org/esa/dsd/dsd_aofw_ni/ni_pdfs/NationalReports/iceland/waste.pdf

[426] Based on interview with IRF, March 2020
[427] Pure North Recycling website, accessible at: www.sorpa.is/en/households/heyrulluplast
[428]

[429] Norwegian Farmers' Association (n.d.). Norwegian Agriculture. Available at: www.bondelaget.no/getfile.php/13894650-1550654949/MMA/Bilder%20NB/Illustrasjoner/Norwegian%20Agriculture%20EN.pdf
[430] APE Europe website: "Statistics: Plasticulture in Europe". Accessible at: http://apeeurope.eu/statistics
[431] Gront Punkt Norway website, accessible at: www.grontpunkt.no/membership/membership-rules
[432] 17 866 tonnes collected, subtracted by 7 147 tonnes when taking into account 40% contamination rate = 10 719 tonnes net material recycled: Gront Punkt Norway website, accessible at: www.grontpunkt.no/om-oss/fakta-og-tall

applications placed on the market in Norway.[433]

A.2.3.4 UK

In 2020, two separate voluntary collection schemes were established to collect agri-plastic waste, with the intention to scale-up the amount of plastic collected from farms nationally:

- **APE UK**: a scheme introduced by the not-for-profit organisation, APE UK based on extended producer responsibility principles, which represents 80% of the major producers of non-packaging agri-plastics in the UK.[434] An Environmental Protection Contribution (EPC) levy of £20 per tonne is charged to producers to cover waste collection and treatment costs.
- **UK Farm Plastic Responsibility Scheme (UKFPRS)**: a scheme launched by several major UK-based collectors. The scheme differs to the APE UK scheme as it is applied by the collectors of agri-plastics, rather than producers. The scheme aims to increase the amount of material collected by harmonising the collective efforts of farm collectors to enable 'no additional costs' to farmers for the collection of their farm plastic. The scheme was partly set up in response to closing export markets and the falling value of used material, as well as in direct response to the APE UK scheme which is perceived as a commercial threat to the current collectors of farm plastics. This is because both schemes aim to increase the amount of agri-plastics which is collected. Thus, if either scheme increased collection rates, the other may collect less. Most collectors in the UKFPRS scheme, representing the significant majority of collectors, do not currently plan to partake in the APE UK scheme.[435,436]

Agri-plastics consumption

The use of agri-plastics in the UK is dominated by livestock farming, corresponding to the following main agri-plastic applications: silage wrap, stretch film, bale net and PP twine, which are all used to wrap and preserve forage. Annually, an estimated 48,950 tonnes of non-packaging agricultural plastics is placed on the UK market (see Figure A2.28).[437] Stretch films (LDPE) account for almost half (47%) of the UK's estimated market share with 23,000 tonnes in 2019. The share of biodegradable plastics used in agriculture is marginal with an estimated 1-2%, at most in the UK.[438]

---

[433] Gront Punkt Norway website, accessible at: www.grontpunkt.no/om-oss/fakta-og-tall

[434] RECOUP Recycling (2019) UK Farm Plastics Scheme Launched. Accessible at: www.recoup.org/news/7822/uk-farm-plastics-scheme-launched

[435] Based on interview with an UK agri-plastics collector, March 2020

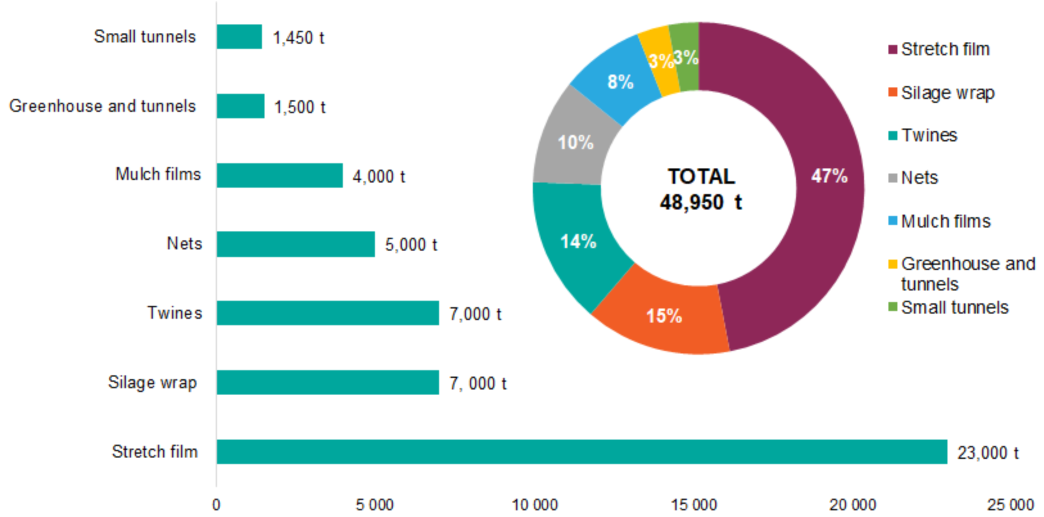
[436] Doherty, J. (2019) "Recyclers launch second farm plastics scheme", accessed 1 April 2020, www.letsrecycle.com/news/latest-news/recyclers-launch-second-farm-plastics-scheme

[437] Based on data provided by APE UK.

[438] Based on interview with an UK agri-plastics collection scheme operator

Concerning the share of biodegradable plastics, the use of biodegradable plastics in agriculture is marginal. There is some use of black corn or potato starch based biodegradable products, such as 'Biotelo', in courgette and sweetcorn crops.[439] This aligns with anecdotal information, with estimates that biodegradable plastic usage in the UK is between 1-2%, at most.[440]

Figure A2.28: Quantity of specific agri-plastic applications placed on UK market (tonnes), 2019



*Source: APE EUROPE *Includes poly-tunnel film – transparent film ** All ground covering films which includes carrot films, mulching films ***Also known as bale wrap **** Includes the weight of contaminants on the plastic*

[439] ADAS UK Ltd (2011) Horticultural crops grown under protection – impact of use of temporary covers and plastic mulches on UK agronomic practice

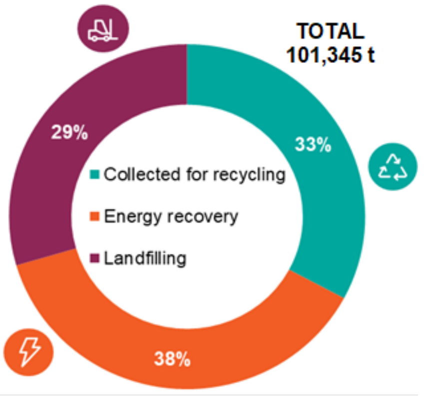
[440] Based on interview with an UK agri-plastics collection scheme operator

End-of-life practices

Limited data is available on how agri-plastics are managed at their end-of-life in the UK due to the absence of national recycling targets and up only until recently dedicated collection schemes for agricultural plastic waste. As a result, estimates on EOL practices are based on available data obtained from APE UK and Waste and Resources Action Programme (WRAP).

Based on APE UK's estimates, the annual quantity of (non-packaging) APW generated in the UK amounts to approximately 101,345 tonnes.[441] Of the APW generated annually, approximately one third (33,268 tonnes) is collected. Based on the total volume of waste generated, the recycling rate in the UK is around 33%. Of the remaining APW not collected for recycling, WRAP (2016) estimated that 56% is sent for energy recovery and 44% sent to landfill.[442]

Figure A2.29: EOL treatment of APW (excl. packaging) in the UK (annual average)



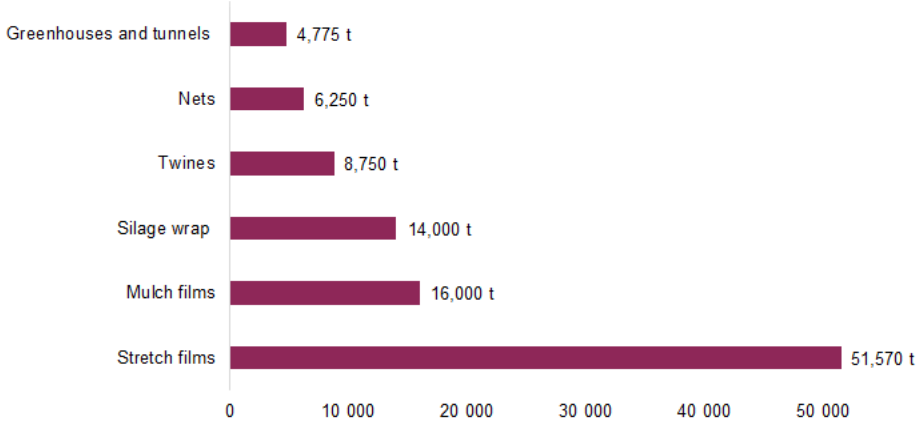
Source: APE UK, WRAP

Based on the estimated quantity of APW generated, Figure A2.29 shows the overall share in regard to EOL practices, indicating that on average 33% of APW is collected for recycling, 38% is used for energy recovery and 29% is landfilled.

It should be noted that the EOL figures presented Figure A2.29 do not reflect estimates on the share of APW that is burned/buried on site, which is prohibited in the UK under the Waste Management Regulations of 2006. However, according to stakeholder input and literature, some farmers still continue to illegally bury or burn their waste to avoid disposal fees.[443,444,]

[441] APE UK estimated the figures for APW generation based on quantities placed on market figures and estimated collection and contamination rates (see Table 5.16 in Appendix).
[442] WRAP and Valpak (2016) Plastics Spatial Flow. Available at: www.valpak.co.uk/docs/default-source/environmental-consulting/plastic_spatial_flow_final_report_20aug.pdf
[443] WRAP and Valpak (2016) *Plastics Spatial Flow*. Available at: www.valpak.co.uk/docs/default-source/environmental-consulting/plastic_spatial_flow_final_report_20aug.pdf
[444] Based on interview with an UK agri-plastics collector, March 2020

Figure A2.30: Estimated annual APW generated (excl. packaging) in the UK



Source: APE UK

APE UK estimated this figure based on conversations with recyclers and collectors over the last two years.

Table A2.16: Average contamination and collection rates, by APW stream in the UK, 2019

Applications	Greenhouse & Tunnels	Small Tunnels	Mulch**	Silages	Stretch films***	Twines	Nets	Total tonnes/ average %
Polymer Type	LDPE	LDPE	LDPE	LDPE	LDPE	PP	HDPE	N/A
Placed on market (tonnes)	1500	1450	4000	7000	23000	7000	5000	48950
Average soilage rate %	125%	200%	400%	200%	225%	125%	125%	207%
Post-use arising's (tonnes) ****	1875	2900	16000	14000	51570	8750	6250	101525
Collection rate	80%	70%	60%	30%	25%	20%	20%	33%
Total volume collected (est.)	1,500	2,030	9,600	4,200	12,938	1,750	1,250	33,268
Total volume not collected (est.)	375	870	6,400	9,800	38,813	7,000	5,000	68,258

*Source: APE UK: *Includes poly-tunnel film – transparent film ** All ground covering films which includes carrot films, mulching films, crop cover ***Also known as bale wrap **** Includes the weight of contaminating material.*

There are three major collectors: Agri-cycle, Solway and Farm XS, alongside a number of other smaller scale collectors operating regionally. A large-scale collection service called

Birch Plastics ceased collecting for economic reasons in 2018.[445] In the significant majority of areas in the UK there is competition for the collection of farmed material. After baling their agri-plastics, collectors in the UK have four options for processing:[446]

1) Selling low value plastics to brokers who source recyclers abroad.
2) Selling high value plastics to re-processors based in the UK.
3) Organising the collection of baled plastic for export. Usually at no profit or cost.
4) Stockpiling plastics (with the intention of collecting enough to sell in bulk).

There is a relatively fragmented collection market in the UK with approximately 70 collectors of agricultural plastics. The methods by which collectors collect and charge for their services varies. Some collectors require a subscription fee to fund their collection services. Subscription fees range from £150 - £400 a year with prices varying according to the size of the farm. In most cases farmers transport their agri-plastics to the collector, however, there is sometimes an option to pay for a collection visit (one collector charges £100 per trip). Other collectors which do not operate on a subscription service model, charge at a per tonne rate for collection.[447]

According to WRAP's *Plastics Spatial Flow* report, much of the agri-plastics that are exported go to Eastern Europe for manual cleaning before returning to the UK for reprocessing.[448]

Despite the UK's Waste Transfer Note (WTN) system, which aims to prevent illicit disposal methods by requiring that farmers obtain a WTN from a licensed waste processor to verify the collection of their agri-plastic waste. According to anecdotal evidence, it is common practice for some farmers to offload only a portion of their agri-plastics to a licensed waste processor and burn or bury the remainder. Generating WTNs in this manner allows farmers to meet legal requirements and save costs incurred by the disposal of their agri-plastic waste.[449] With the recent closure of the only company dedicated to collecting agri-plastic waste across Wales (Birch Plastics), it is likely that this problem may become more prevalent in Wales.[450]

Agri-plastics production

In 2006, a total of 24 producers / importers of agri-plastics are known to have supplied the UK market and, in terms of tonnages, an estimated 66% was produced in the UK and 34% imported. Six companies accounted for 94% of this market share.[451] Whilst more

---

[445] Based on interview with a UK plastic producer/recycler, March 2020
[446] Based on interview with a UK agri-plastics collector, March 2020
[447] Based on interview with a UK agri-plastics collector, March 2020
[448] WRAP and Valpak (2016) *Plastics Spatial Flow*. Available at: www.valpak.co.uk/docs/default-source/environmental-consulting/plastic_spatial_flow_final_report_20aug.pdf
[449] BBC News (2019) Farmers could 'burn or bury' plastic
[450] BBC News (2019) Farmers could 'burn or bury' plastic
[451] Valpak and ADAS (2007) Agricultural Waste Plastics Collection and Recovery Programme, June 2007

recent data is not available, anecdotal evidence suggests that the UK producer's current market share may have slightly reduced to between 40-50%. British Polymer Industries (BPI) is the largest supplier of APs in the UK.[452] For mulch film, there is only one facility in the UK, which can wash and shred this material: Peter Allison Agriservices, based in Scotland.

Trends and regional usage

There is little data on regional consumption of agri-plastics in the UK. One study by APE UK concluded that farms in Wales consume an average of 1.1 tonnes of plastics, annually. However, these farms are using plastics associated with silage production. As such, this figure is not applicable in other regions (e.g. south east England), where farms are usually larger and use more plastics associated with horticultural practices. In the absence of regional consumption data, and based on 2006 waste generation data, the regions with the highest silage wrap consumption are assumed to be:[453]

1) Scotland: 17% of UK consumption of silage wrap
2) Southwest England: 14% of UK consumption of silage wrap
3) Wales: 12% of UK consumption of silage wrap
4) N Ireland: 11% of UK consumption of silage wrap

As stretch films, bale nets and twines are used in conjunction with silage wraps, trends in regional consumption of these agri-plastic applications are likely to correspond with the consumption of silage wraps.

Market trends

An estimated 85% of the 9,400 ha of land used to grow soft fruit in the UK is grown under greenhouses and small tunnels (also called poly-tunnels).[454] Whilst recent time series data for the use of crop covers was not found, a 2011 report for the Government Department for Environment, Food and Rural Affairs (Defra) sought to determine the amount, and identify trends for, the types of crop covers used in the UK and reasons for their use. The report indicated that crop cover use was growing in the early 2000s – with a significant increase of crop covers in soft fruit and cane fruit production. According to the report, in 2003, 30% of total soft fruit and cane fruit production used crop covers, rising to at least 70% in 2009. This occurred alongside a growing area of land in the UK which was used for fruit production. For example, the area of strawberries grown in the UK doubled between 2004 and 2011. In 2019, it was estimated that around 7,000 tonnes of LDPE crop covers was placed on the UK market (Figure A2.28).[455]

[452] Based on interview with an UK agri-plastics collector, March 2020
[453] Valpak and ADAS (2007) *Agricultural Waste Plastics Collection and Recovery Programme*, June 2007
[454] Alman Hall (2019) Overview of the strawberry industry, accessed 6 March 2020, https://allmanhall.co.uk/blog/overview-of-the-strawberry-industry-in-the-uk
[455]Based on interview with an UK agri-plastics collection scheme operator

The ability to mitigate the effects of the UK weather by the use of covers allows the country to compete in the European market.[456] As such, agricultural films e.g. mulching films, covers for greenhouse and tunnels (together referred to as 'crop covers') are increasingly used in the UK, with a high percentage used for fruit production.[457]

There is a relatively fragmented collection market in the UK with approximately 70 collectors of agricultural plastics. There are three major collectors: Agri-cycle, Solway and Farm XS, alongside a number of other smaller scale collectors operating regionally. A large-scale collection service called Birch Plastics ceased collecting for economic reasons in 2018.[458] In the significant majority of areas in the UK there is competition for the collection of farmed material. The methods by which collectors collect and charge for their services varies. Some collectors require a subscription fee to fund their collection services. Subscription fees range from £150 - £400 a year with prices varying according to the size of the farm. In most cases farmers transport their agri-plastics to the collector, however, there is sometimes an option to pay for a collection visit (one collector charges £100 per trip). Other collectors which do not operate on a subscription service model, charge at a per tonne rate for collection.[459] The collection scheme run by APE UK charges a £20 per tonne Environmental Protection Contribution (EPC) levy, which they add on to the sales invoices of their agricultural plastic products. This fund is directed to APE UK which they use to support the scheme, including the collection of material from farmers and investments which improve waste collection infrastructure. APE UK are in the initial stages of work with a waste management company to provide a network of collection hubs throughout the UK. Ultimately, farmers which purchase plastics from these producers pay the levy. In theory, having paid the levy, farmers are less likely to dispose of the waste illegally or by landfill / incineration. In addition, the new collection options financed by APE UK will allow farmers to more easily offload their agri-plastics.[460]

Table A2.17 indicates the approximate market values/prices for various re-processed (recycled) polymers that are used in specific agri-plastic applications. This price is influenced by the contamination rate per polymer. A minority of collectors manage to sell LLDPE silage film waste for small costs – with a maximum of £15 /tonne, or transfer it to brokers at no profit/expense.[461]

---

[456] ADAS UK Ltd (2011) Horticultural crops grown under protection – impact of use of temporary covers and plastic mulches on UK agronomic practice
[457] Includes temporary tunnels
[458] Based on interview carried out with a UK plastic producer/recycler, March 2020
[459] Based on interview carried out with a UK agri-plastics collector, March 2020
[460] Based on interview with a UK agri-plastics collector, March 2020
[461] Based on interview carried out with a UK agri-plastics collector, March 2020

Table A2.17: Value of re-processed polymers used in agri-plastic applications

Application	Silage film	Woven nets	Spray Cans	Bale Twine
Polymer type	LLDPE	PP	HDPE	PP
Average value per tonne	£5-£7/tonne	£80/tonne	£230/tonne	£200/tonne

Source: UK agri-plastics collector; once they have been collected, cleaned and baled

A.3.0 Supporting Technical Information - Conventional Plastics

A.3.1 ADIVALOR Sorting and Preparation Instructions

Table A3.1: Breeding Plastics – Sorting and Preparation Instructions

Type	Maximum undesirables	Instructions
Silage sheets (polyetheylene underlayer)	20%	Swept dry, folded, rolled and tied
Silage sheets (polyamide underlayer)	20%	Separate the two layers, sweep, fold, roll and tie the tarp. Pack the polyamide film in the blue bags by your distributor
Wrapping films (all colours)	15%	Clean, dry, cleared of vegetable debris
Plastic strings	20%	Clean and free of plant debris as much as possible
Round bale nets	40%	Clean and shaken

Table A3.2: Market Gardening Films – Minimum technical requirements

Type	Maximum undesirables	Instructions
Greenhouses and large tunnels	20%	Fold the film and cut the buried part which is taken up with the other market gardening films. Greenhouses: crush the vegetation, possibly wait a few days to accelerate its decomposition
Small tunnels	40%	Pass a blade to dig up the plastic Manual removal: Shake to remove plants and soil. Recover the mulch and the irrigation sheath separately Machine removal: Lift the hems to remove the soil. Wind the plastic with a type machine two-cone with a beater. Collect the mulch and the irrigation sheath separately. Do not use chucks
Mulching (clear)	50%	
Mulching (coloured)	50%	
Mulching (above-ground)	20%	
All films: Minimize the presence of organic waste; Deposit films, preferably in dry weather, to prevent sand or soil from sticking to the plastic Store on a flat, clean and accessible area in all weathers for dump trucks Do not mix with other classes of agricultural film - twine, nets, flexible irrigation hose nor with bags of fertilizer or substrates		

A.3.2 RAFU Technology[462]

The below photographs represent the RAFU technology in practice.

[462] https://www.youtube.com/watch?v=FPDnJfoI7b0

Figure A3.1: Comparison of Contamination Rate for Traditional Removal Conditions vs RAFU Technology for Carrot Mulch[463]

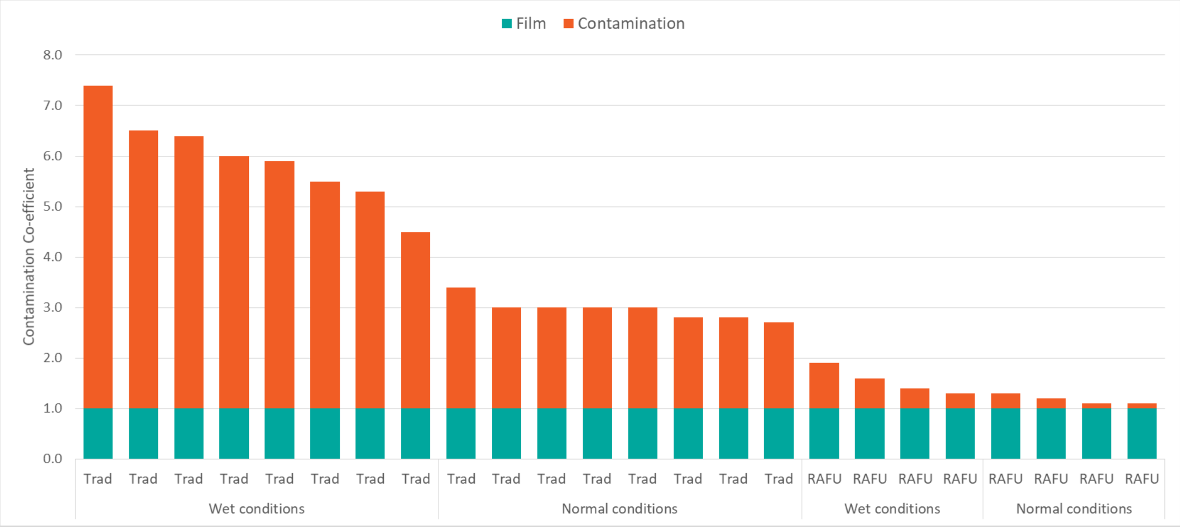


Figure A3.1 shows a graph presented by ADIVALOR in a 2019 presentation. It indicates that the use of the RAFU technology for removal of carrot mulch films can significantly reduce the contamination rate, when compared to traditional removal technologies. This is the case in both wet and normal conditions.

[463] ADIVALOR (2019) Reach 100% Recycling of Mulch Films - Is It Possible?, 2019

A.4.0 Supporting Technical Information- Biodegradable Plastics

A.4.1 Agronomic Performance of BDMs vs Conventional Plastic Mulches per Crop

Tomatoes for processing	
Growing season length	5 months: Spring to early autumn
Agronomic technology	Open field - is not possible to harvest this crop mechanically when LDPE film is used as fragments of film contaminate the harvest.[464]
Locations where currently used	Italy, Spain and France (for 10 years) Spain; In Navarra region of Spain 80% of the 2000 hectares of processing tomatoes currently use BDMs. – supported by administration financial incentives. Italy; especially in the South where it has been promoted by a regional organisation.[465]
Yield under BDM equivalent to PE	Mater Bi in Spain[466] [467] [468] in Italy[469] and in the USA[470] Bioflex and biofilm in Spain[471] [472]

[464] Novamont (2020) QAmulch_March_20.pdf
[465] Novamont (2020) QAmulch_March_20.pdf
[466] Martin-Closas L, Bach A, Pelacho AM et al (2008) Biodegradable mulching in an organic tomato production system. Acta Hortic 767:267–274
[467] Armendariz R, Macua JI, Lahoz I et al (2006) The use of different plastic mulches on processing tomatoes. Acta Hortic 724:199–202

[468] Moreno MM, Moreno A, Mancebo I (2009) Comparison of different mulch materials in a tomato (Solanum lycopersicum L.) crop. Span J Agric Res 7:454–464

[469] Candido V, Miccolis V, Castronuovo D et al (2006) Mulching studies in greenhouse by using eco-compatible plastic films on fresh tomato crop. Acta Hortic 710:415–420
[470] Cowan JS, Miles CA, Andrews PK et al (2014) Biodegradable mulch performed comparably to polyethylene in high tunnel tomato (Solanum lycopersicum L.) production. J Sci Food Agric 94:1854–1864
[471] Martin-Closas L, Bach A, Pelacho AM et al (2008) Biodegradable mulching in an organic tomato production system. Acta Hortic 767:267–274

[472] Cirujeda A, Aibar J, Anzalone A et al (2012) Biodegradable mulch instead of polyethylene for weed control of processing tomato production. Agron Sustain Dev 32:889–897

Yield worse under BDM	No studies found
Weed control	Weed control satisfactory with mulches that remain without breakages for 60 days.[473] Paper mulches, straw mulches, manual weeding and herbicides all controlled weeds as much as LDPE 15 µm[474]
Earliness	Italian study found that 15-20 µm photo-selective green film increased soil temp in early stages, obtaining fast growth of seedlings and root development. [475]
Suitable for BDM's?	Yes.

Fresh Tomatoes	
Growing season length	5 months: all year round when in tunnels or greenhouses
Agronomic technology	Open field / large tunnels /greenhouses
Locations where currently used	Italy, Spain, France, Australia, USA, Canada

[473] Martin-Closas L, Bach A, Pelacho AM et al (2008) Biodegradable mulching in an organic tomato production system. Acta Hortic 767:267–274
[474] Anzalone A, Cirujeda A, Aibar J et al (2010) Effect of biodegradable mulch materials on weed control in processing tomatoes. Weed Technol 24:369–377
[475] Novamont (2020) QAmulch_March_20.pdf

Yield under BDM equivalent to LDPE	Ecoflex 25µm black[476] Spain; open air, Green and Brown BDMs 16-25 µm produced yields equivalent to LDPE 15-30µm.[477] USA; EcoPlanet black 12.7µm produced yields equivalent to black LDPE 20µ[478] China; in a greenhouse in summer BDMs performed better than LDPE – thought to be because of heat stress in summer conditions.[479]
Yield worse under BDM	White Ecoflex[480]
Other effects	Weed control in a greenhouse crop equivalent to LDPE mulch (MB 12 and 15 µm) [481]
Other notes	Paper mulches also produce yield equivalent to BDMs[482][483] Spunbond non-woven also found to produce equivalent yields [484]
Suitable for BDM's?	Yes

[476] Ngouajio1 M, Auras R, Fernández RT et al (2008) Field performance of aliphatic-aromatic copolyester biodegradable mulch films in a fresh market tomato production system. HortTechnology 18:605–610
[477] Moreno, M.M., and Moreno, A. (2008) Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop, *Scientia Horticulturae*, Vol.116, No.3, pp.256–263
[478] Alamro, M., Mahadeen, A., and Mohawesh, O. (2019) Effect of degradable mulch on tomato growth and yield under field conditions, *Bulgarian Journal of Agricultural Science*, Vol.25, pp.1122–1132
[479] Zhang, X., You, S., Tian, Y., and Li, J. (2019) Comparison of plastic film, biodegradable paper and bio-based film mulching for summer tomato production: Soil properties, plant growth, fruit yield and fruit quality, *Scientia Horticulturae*, Vol.249, pp.38–48
[480] Ngouajio1 M, Auras R, Fernández RT et al (2008) Field performance of aliphatic-aromatic copolyester biodegradable mulch films in a fresh market tomato production system. HortTechnology 18:605–610
[481] Candido V, Miccolis V, Castronuovo D et al (2006) Mulching studies in greenhouse by using eco-compatible plastic films on fresh tomato crop. Acta Hortic 710:415–420

[482]Martin-Closas L, Bach A, Pelacho AM et al (2008) Biodegradable mulching in an organic tomato production system. Acta Hortic 767:267–274

[483] Cirujeda A, Anzalone A, Aibar J et al (2012) Purple nutsedge (Cyperus rotundus L.) control with paper mulch in processing tomato. Crop Prot 39:66–71
[484] Wortman SE, Kadoma I, Crandall MD (2015) Assessing the potential for spun-bond, nonwoven biodegradable fabric as mulches for tomato and bell pepper crops. Sci Hortic 193:209–217

Peppers and aubergines	
Growing season length	5 months: all year round when in tunnels or greenhouses; They are more demanding crops for temperature so transplanted from late spring to early summer. Mulching is frequently used to advance transplanting.
Agronomic technology	Open field/ tunnel.
Locations where currently used	Italy, Spain, France, Australia, USA, Canada
Yield under BDM equivalent to LDPE	Australian study with peppers, MB 12 and 15µm compared with LDPE mulch 25µm. [485]
Yield worse under BDM	Spubond nonwoven PLA did not increase pepper yield relative to bare soil.[486]
Other notes	Growth pattern of pepper plants (erect with thin leaves) increases exposure of the BDM to environmental factors thus resulting in more degradation during use phase than with other crops such as tomatoes. [487]
Suitable for BDM's?	Yes

Lettuce	
Growing season length	2 – 3 months
Agronomic technology	Open Field
Locations where currently used	Spain, Italy, France, Germany

[485] Olsen JK, Gounder RK (2001) Alternatives to polyethylene mulch film, a field assessment of transported materials in capsicum (Capsicum annuum L.). Aust J Exp Agric 41:93–103
[486] Wortman SE, Kadoma I, Crandall MD (2015) Assessing the potential for spun-bond, nonwoven biodegradable fabric as mulches for tomato and bell pepper crops. Sci Hortic 193:209–217
[487] Martín-Closas, L., Costa, J., and Pelacho, A.M. (2017) Agronomic Effects of Biodegradable Films on Crop and Field Environment, in Malinconico, M., (ed.), *Soil Degradable Bioplastics for a Sustainable Modern Agriculture* (2017) Berlin, Heidelberg: Springer Berlin Heidelberg, pp.67–104

Yield under BDM equivalent to PE	MB 12 and 15µm produced equivalent yields to LDPE 25-50 µm in open field trial.[488]
Yield worse under BDM	Greenhouse summer trial in Spain leaf development more with LDPE mulches and yields higher – suggested due to the higher soil temperatures under the BDMs.[489]
Suitable for BDM's?	Yes.

Strawberries	
Growing season length	6-12 months; Autumn to winter crops 9-12 months
Agronomic technology	Open field with small tunnel/tunnel
Locations where currently used	Italy, Spain, Belgium, Germany, Scandinavian countries where crops are on an annual cycle
Yield under BDM equivalent to PE	An early study in Italy recorded higher yields and earlier crops with MB film 25-45µm compared with LDPE film 50 µm. [490] A recent study in Campania, Italy with MB produced a *better* yield than LDPE and increased quality. [491] Portugal study, in open field and greenhouse trials; no differences in yield was found between LDPE 35 µm and MB 18 µm[492]
Yield worse under BDM	Portugal, MB 20-30 µm, white on black, yields 20-37% lower than LDPE film – thought to be because the BDM warmed soils more than the LDPE mulch during summer months. [493]

[488] Minuto G, Pisi L, Tinivella F et al (2008) Weed control with biodegradable mulch in vegetable crops. Acta Hortic 801:291–297
[489] Lopez-Marin J, Abrusci C, Gonzalez A (2012) Study of degradable materials for soil mulching in greenhouse-grown lettuce. Acta Hortic 952:393–398
[490] Scarascia-Mugnozza, G., Schettini, E., Vox, G., Malinconico, M., Immirzi, B., and Pagliara, S. (2006) Mechanical properties decay and morphological behaviour of biodegradable films for agricultural mulching in real scale experiment, *Polymer Degradation and Stability*, Vol.91, No.11, pp.2801–2808
[491] Novamont (2020) QAmulch_March_20.pdf
[492] Costa, R., Saraiva, A., Carvalho, L., and Duarte, E. (2014) The use of biodegradable mulch films on strawberry crop in Portugal, *Scientia Horticulturae*, Vol.173, pp.65–70
[493] Andrade, C., Palha, M., and Duarte, E. (2014) Biodegradable mulch films performance for autumn-winter strawberry production, *Journal of Berry Research*, Vol.4, pp.193–202

Suitable for BDM's?	Yes, using black film with a minimum thickness of 18-20 µm But issues have been found when crops are fumigated soon before mulch applied.

Cucurbit crops- Melon, Watermelon, Courgette, Pumpkin, Cucumber	
Growing season length	Spring -summer crops needing higher temperatures than tomato – main purpose of mulch is to accelerate harvest. Clear mulches are most suitable for this as they
Agronomic technology	Open field
Locations where currently used	Spain, Italy, Greece 7000ha in Spain growing melons – most not currently using BDMs
Yield under BDM equivalent to PE	Melons cultivated in a greenhouse in Italy, -study reported similar yield and fruit quality with clear LDPE film 50µm and MB 25µm. Spain; melons in open field, clear BDMs (MB 18µm) produced an equivalent yield to LDPE (25µm).[494] Canada; cantaloupe melons, equivalent marketable yield obtained with MB 15µm and LDPE 28µm. Clear films produced higher yields than black ones.[495]
Yield worse under BDM	No studies found
Suitable for BDM's?	Yes

---

[494] Gonzalez A, Fernandez JA, Martin P et al (2003) Behaviour of biodegradable film for mulching in open-air melon cultivation in South-East Spain. Biodegradable materials and fiber composites in agriculture and horticulture. KTBL-Schrift, Darmstadt, pp 71–77

[495] Limpus S, Heisswolf S, Kreymborg D et al (2012) Comparison of biodegradable mulch products to polyethylene in irrigated vegetable, tomato and melon crops. Department of Agriculture, Fisheries and Forestry. Final report Project MT09068. Horticulture Australia Ltd., Sidney

A.4.2 Comparison of European, French and Italian Biodegradable Mulch Film Standards

The Italian (UNI 11495), French (NF U52-001) and European mulch film standards (EN 17033) largely follow the soil biodegradation test laid out in EN ISO 17556. This test measures the evolved carbon dioxide as an indicator of biodegradation. The intrinsic biodegradation is calculated by comparing the actual evolved CO_2 with a calculated value for the theoretical amount of CO_2 evolution possible to give a percentage. (The evolved CO_2 recorded in the cellulose reference material is subtracted from the evolved CO_2 of the test material). The test is considered completed when a constant level of evolved CO_2 is attained, and no further biodegradation is expected. The test period should typically not exceed 6 months, but if plateau phase is not reached it can be extended to no more than 24 months.

In order to turn this test method into a standard that ensures that a product will in fact biodegrade sufficiently under soil conditions, validity criteria are included in EN 17556. The biodegradation rate recorded in the test must be above a certain threshold, and this must be achieved within a certain timeframe. The test is considered *valid* if the reference material (cellulose) has biodegraded by more than 60% at the plateau phase or at the end of the test; and the evolved CO_2 levels are within 20% of the reference material value. The testing pass threshold is designated by the relevant standards as seen in Table A4.1. For the European and Italian standards, the test is considered to be *passed* if 90% biodegradation is reached either relative to the reference cellulose material or in absolute terms over 24 months, whereas the French standard required 60% in 12 months.

Table A4.1: Biodegradation Test Specifications of Mulch Film Standards

Standard Number	Tests referenced	Validity criteria	Temperature	Soil specifications
EN 17033:2018 (Europe)	EN ISO 17556	90% biodegradation in comparison to cellulose reference or in absolute terms within 24 months	constant within ±2°C in the range between 20-28°C, preferably 25°C	As in ISO 17556 - natural soil from fields or forests, sieved to less than 5mm preferably 2mm Or 'standard soil' [496]
NF U52-001 2005 **(France)**	Water - EN ISO 14851 or 14852 Soil - No test referenced (annex F) Compost -NF EN 14046	For soil test: 60% biodegradation in comparison to cellulose reference in 12 months	28°C ±2°C	Natural soil from a field, sieved to 2mm
UNI 11495 2013 (based largely on UNI 11462 2012) **(Italy)**	EN ISO 17556 or test in Annex A	90% biodegradation in comparison to cellulose reference in 24 months	21-28°C	Natural soil from a field, sieved to 2mm

The French standard does not reference ISO 17556 but follows a very similar method with the slight change in specifying that the reference material must be 70% degraded after 6 months which is a slightly stronger requirement. However, the validity requirement for the test material is then only 60% in relation to this reference material.

The French standard differs from the others as it specifies three possible media for testing products; water, soil and compost, with different biodegradation percentages in each (90% in water, 60% in soil, and 90% in compost). A product can be validated by this standard if the minimum values for biodegradability are reached in two of the three mediums. Technically, this means a product could be certified as valid for biodegradable in soil without passing this threshold; in practice, the water requirement is likely to be a harder test to pass and more complex to test.

[496] consisting of industrial quartz sand, Kaolinite clay, natural soil, and mature compost (serving as organic carbon source)

Table A4.2: Ecotoxicity Tests Within Mulch Film Standards

Standard	Chemical Limits	Toxicity Testing			Concentration of Material in Soil
		Plant growth	Earthworms	Microorganisms	
EN 17033	heavy metals, Substances of Very High Concern <0.1% of weight (EN 17294)	Seedling Emergence and Seedling Growth Test OECD 208 (annex B modifications)	ISO 11268-1 (annex C) or ISO 11268-2 (annex D)	bacteria - nitrification inhibition ISO 15685 (annex E)	1% (recommended to test in a powdered form)
NF U52-001	limits for heavy metals, PCB and PAH content	Plant germination and growth: ISO 11269 Growth inhibition test with green algae NF T 90-375	FD X 31-251	none	amount of mulch film equal to the dose used in a field X 100.
UNI 11495	limits for heavy metals	seed germination and growth of plants UNI 1078, daphnia ISO 6341,	ISO 11268-1	none	1% plastics

A.4.3 Accumulation Projections

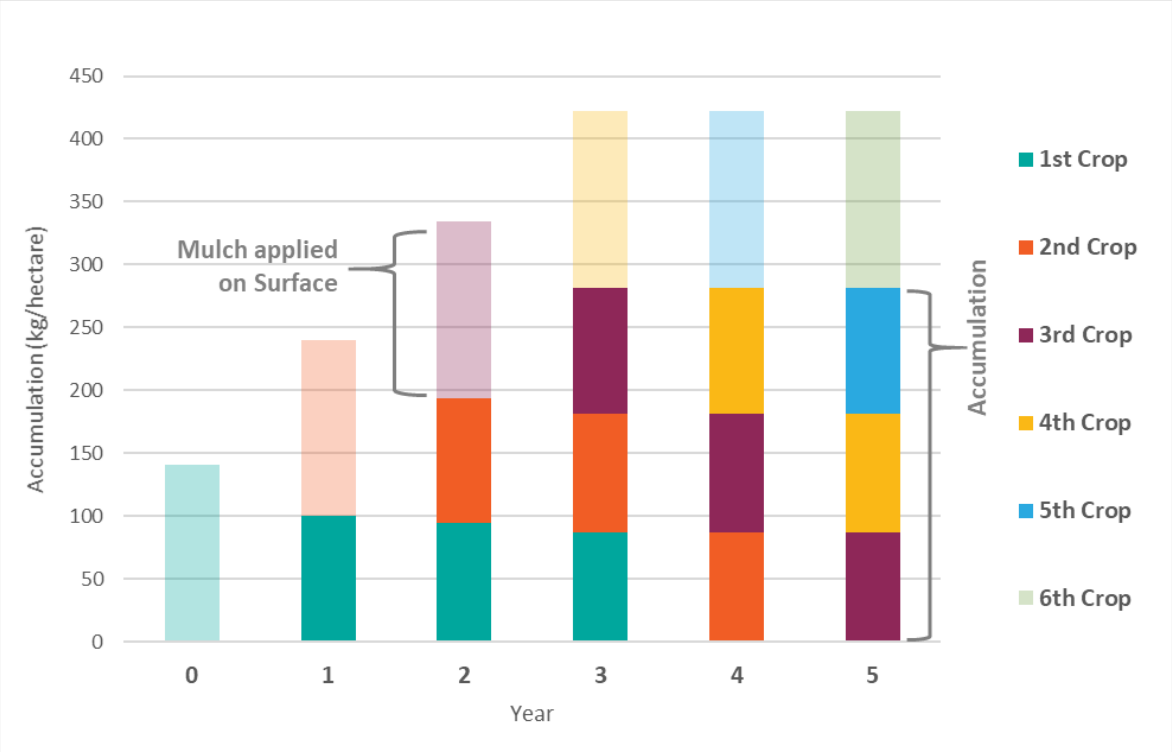
Accumulation projections are taken from the work by Ghimire conducted between 2016 and 2019.[497] The study used four different types of BDMs over the course of four planting seasons and each time measuring the remaining plastic in the soil to calculate the accumulation potential. Figure A4.1 is adapted from the results to model how accumulation might look over several years. It assumes an average thickness of 15µm and a density of 1,250 kg/m^3. With field coverage of 75% the mass per hectare is 141 kg (incidentally a 20 µm LDPE film has a mass of 139 kg/hectare due to its lower density).

Ghimire presented results for several different films with sampling points in both Spring—just before mulch application—and Autumn—just after tilling. Unfortunately, much of the data is inconsistent or difficult to assign specific trends to which is likely due

[497] Ghimire, S., Flury, M., Scheenstra, E.J., and Miles, C.A. (2020) Sampling and degradation of biodegradable plastic and paper mulches in field after tillage incorporation, *Science of The Total Environment*, Vol.703, p.135577

to the difficulty in accurately sampling plastic in soil. A robust and repeatable method for this has still to be designed. Nevertheless, the data for the average remaining film residue in Spring is consistent enough to show the trend in Figure A4.1. The key data is that 71% of the applied material was recovered in the first year, 50% in the second year and 35% in the third year. Table A4.3 shows how these figures were used – note that years two and three are adjusted to equal 100% biodegradation over three years.

Figure A4.1: Model of Biodegradable Plastic Accumulation



Source: Adapted from Ghimire et at (2019)

Table A4.3: Accumulation Calculation Method

(red = applied mulch, yellow= residue in soil)

	Year 0	Year 1	Year 2	Year 3
1st Crop	**141**(i)	**100**(ii)	**53** (iv)	
2nd Crop		**141** (iii)	**100** (v)	**53** (vii)
3rd Crop			**141** (vi)	**100** (viii)
Total Remining in Soil		**71%** (ii/i)	**55%** (iv+v/i+i)	**36%** (vii+viii/i+iii=vi)

A.5.0 Summary of Approach to Modelling Impacts

The following sections present the methodology used for modelling the impacts of proposed changes in policy.

Section A.6.0 sets out the approach taken to the preparation of the baseline of projected flows of agricultural plastics in Europe, from the point of consumption to end of life management ().

Section A.7.0 describes the approach taken to modelling the impacts of selected policy scenarios on agricultural plastic consumption and waste management, costs to farmers and producers and environmental impacts ().

The purpose of this modelling is to provide an indication of potential impacts on different stakeholders based on the best available information. The reader should note that detailed statistical reporting of much of the data required for this study is relatively undeveloped. This has necessitated the use of carefully considered estimates and assumptions for some inputs and modelling parameters. These are noted throughout this report, and wherever possible have been evidenced in reference to known data points.

A.6.0 Preparation of the Baseline

The baseline provides an overview of agricultural plastic consumption, waste generation, collection and management for EU28 Member States. It includes both existing historic data and future projections out to 2040. The baseline is essentially a "no policy change" scenario, i.e. modelling of future trends include all relevant EU-level and national policies and measures which are assumed to continue in force, including the impact of national collection schemes. The modelled impact of any national collection schemes with a confirmed implementation date are also included.

A.6.1 Historic Data

The main source of historic data for this study was Agriculture Products Europe (APE Europe), who provided the following agricultural plastics tonnage data for the EU28:[498]

- Placed on the market / Consumption (2015 and 2019 data)
- Waste generation (2019 data)
- Collected waste (2019 data)
- Final recycling (2019 data)

Table A6.1:Baseline Data Taxonomy

Category	Application	Segment	Polymer
Films	Greenhouses	Crop production	LDPE
	Mulch film	Crop production	LDPE
	Small tunnels	Crop production	LDPE
	Stretch film	Livestock production	LDPE
	Silages	Livestock production	LDPE
	Non-woven nets	Crop production	LDPE
Nets	Protective nets	Crop production	HDPE
	Bale net	Livestock production	HDPE
Pipes	Irrigation pipe	Crop production	LDPE
	Drippers	Crop production	LDPE
Twines	Twine	Livestock production	PP

[498] APE Europe (2020) *Plastics Data*

Category	Application	Segment	Polymer
Bio/Oxo-degradable Films	Biodegradable mulch films	Crop production	-
	Oxo-degradable agri-plastics	Crop production	-

This data was supplemented with additional data on yield/loss rates from responses to the questionnaire sent to Plastics Recyclers Europe (PRE).

Less data was available for other waste management destinations: landfill, incineration and reuse. No quantitative reuse data was available, although existing literature on agricultural plastics reuse is discussed qualitatively in Section 2.5.4.2.

Some agricultural plastic waste is not collected through national collection schemes. Within the data supplied by APE Europe there is a 419 kt difference between the quantity of waste generated across Europe (1,175 kt), and collected (756 kt). This waste may be managed in a variety of ways, including:

1) Collected for landfill and recycling with local solutions (not related to national collection schemes);
2) Unwanted disposal methods (e.g. burnt on-site); and
3) Left in the environment.

There is very little available data on the proportion of waste going to each of these destinations, although there is some literature which discusses the amount of plastic left in the environment for a limited number of applications. In our results (Section 8.1), this 'unaccounted for' waste, i.e. waste not collected through national collection schemes, is included as a distinct final destination. 'Unaccounted for' waste includes plastic, an unknown fraction of soil, and any other contaminants presented in generated waste.

As discussed in Section 2.5.4.5, it is estimated in France that 5% of agricultural films that were not collected were burnt, and 15% for nets and twines. We have used these estimates in the model to disaggregate waste burnt openly from other 'unaccounted for' destinations. The reader should note that no further data points for open burning were available in the literature, and so reliance on a single data point does introduce significant uncertainty.

A.6.2 Forward Projections

A.6.2.1 Placed on the Market / Waste Generated

Future changes in consumption where modelled in one of two ways:

1) Based on future market projections discussed in the literature;[499]
2) Where projections are not available, based on the average annual growth rate in data from 2015 to 2019, and with growth no higher than the average growth for all agricultural plastics over this period (based on APE Europe data).

This approach ensures that existing expert view on the evolution of the market are taken into account, and, where these are not available, that a conservative assumption on growth is used which uses a suitable methodology to minimize anomalously high growth rates (which may be an artefact of data uncertainties).

Annual growth rates are applied from the latest year (2019) until 2030. We consider it too speculative to assign growth rates to the period from 2030 to 2040, and thus it is assumed that consumption will stay constant over this period. The growth rates applied from 2019 to 2030 are presented in Table A6.2.

Table A6.2: Modelled Annual Growth Rates for Agricultural Plastics Placed on the Market / Consumption for 2019 to 2030

Application	Modelled Growth Rate
Greenhouses	-0.5%
Mulch film	-0.5%
Small tunnels	1.5%
Stretch film	1%
Silages	1%
Non-woven nets	1.5%
Protective nets	1.5%
Bale net	1%
Irrigation pipe	1.5%
Drippers	0%
Twine	1%
Biodegradable mulch films	8%
Oxo-degradable agriplastics	N/A - Banned in July 2021

[499] Plasteurope (2014) *Agricultural films*, https://www.plasteurope.com/news/AGRICULTURAL_FILMS_t228787/

Biodegradable mulch films are modelled with a higher growth rate than other applications. This is based on the view of APE Europe that the share of these products should not exceed 10-15% of total mulch films consumption.

Oxo-degradable plastics present a special case, in that their sale and use is banned in the EU under the Single-Use Plastics Directive from July 2021. We have modelled that consumption of these plastics will gradually decline, until reaching zero in July.

The proportion of waste generated compared to placed on market data in available data for 2019 is assumed to stay fixed in future years. This reflects the assumption that average contamination rates of agricultural plastics with soil are expected to stay relatively constant.

A.6.2.2 Collection Rates

There are no current policies at the EU level which stipulate targets or otherwise for the improved management of agricultural plastics waste. The overarching policy driving improvements in waste management (including agricultural waste) is Article 11 of the Waste Framework Directive, which states that Member States:[500]

> *shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors*

Where Member States do not already meet the stipulations of this article i.e. they do not provide separate collections for agricultural plastic waste where technically, environmentally and economically practicable, we assume that EPR schemes provide a route to doing so. Furthermore, there are no overarching collection targets or similar for agricultural plastic wastes in the EU, and thus any increase in collection rate is assumed to be a consequence of improvements in EPR schemes.

Six EU countries have used legislation to implement national collection schemes for agricultural plastics, bringing together users, distributors and producers.[501] The UK and Spain (Andalusia) have agreed to implement schemes in 2020.

Baseline projections assume that these schemes continue into the future, and drive collection rates towards those observed in the best-performing schemes. We have assumed that collection rates of 80% will be achieved for mandatory EPR schemes, and 70% for voluntary schemes. These collection rates are based on what is currently being achieved by existing schemes, for example:

- **Mandatory:** IFFPG reported a 79% collection rate for silage wrap and sheeting in 2019. A representative from the scheme suggested it is very challenging to

[500] Official Journal of the European Union (2008) *DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, 19th November 2008, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

[501] France, Germany, Ireland, Italy and Sweden all have national collection schemes for agricultural plastics.

increase collection rates beyond ~80%, as there will always be a small number of farmers who will not participate for various reasons;

- **Voluntary:** ADIVALOR reported an average collection rate of 67% in 2019.
- **Voluntary:** ERDE reported a 37% collection rate for silage wrap and sheeting in 2019 (note that the scheme only launched in 2013/14). It is targeting a 50% collection rate by 2020 and a 65% collection rate by 2022. A representative from the scheme considered the 2022 target (65%) was ambitious, and that a target of 70 – 75% collection rate would be maximum for both voluntary and mandatory schemes.

Certain design features in a mandatory scheme may lead to higher collection rates compared to a voluntary scheme, for example:

- Legally binding collection targets drive scheme performance.
- Minimum coverage requirements ensure the scheme is convenient for all.
- Full EOL net costs are covered in producer fee, so no charge to farmers at point of collection

These rates are assumed to be achieved over the same timescales used for policy scenarios (see Section 8.0), i.e. within 7 years (by 2027) for mandatory schemes, and within 9 years (by 2029) for voluntary schemes. Rates are increased by an equal amount year on year over these time periods, i.e. using an arithmetic progression.

It should also be noted that these collection rates apply (and are modelled to apply in the future) only for those applications within the scope of the scheme, as set out in Section 2.6. The schemes are not modelled to expand in scope in the baseline as there is no current or proposed basis in existing legislation on which to do so.

These overall collection rate targets for applications in the scope of EPR schemes are used to model collection rates for individual plastic applications (e.g. stretch film). These are increased with a fixed arithmetic progression, and are limited to a maximum of 95%. It is also assumed that applications which are not currently recycled (mulch films and bale nets), will continue to only go to residual waste treatment in the future.

A.6.2.3 Waste Management Destinations

It is assumed that the relative proportions of plastic and soil in collected waste remain constant in the future. Data from APE Europe shows, for the mix of agricultural plastic waste types in the EU, an average of 41% of collected waste is soil (i.e. a maximum of 59% of collected waste can be recycled, averaged across all agricultural plastic waste types).

Collected waste (both plastic and soil components) is either sent to recycling or sent to residual disposal at landfill site or incineration plants. Soil cannot be recycled and is generally landfilled. For collected wate sent for recycling, there are losses at both sorting facilities and reprocessors, and thus the final amount of plastics recycling is lower than the amount of plastic (excluding soil) collected for recycling.

Available data on the treatment routes of plastic waste is scarce and the methodology by which this data is derived is often not clearly described. Current yields (i.e. the percentage of collected waste that is recycled) in the baseline are based on values reported in the PRE questionnaire. These data state that on average 70% of greenhouse films, 50% of silage films, and 30% of stretch films collected in the EU are recycled at present, with negligible recycling of nets, pipes, and twine.

Future yields of recycled plastic from collected waste are modelled in a similar manner to collection rates. We have assumed that best-practice rates will be achieved within 7 years (mandatory EPR), and within 9 years (voluntary EPR) for Member States with existing or planned national collection schemes. That is, where existing (or planned) national collection schemes currently send waste directly to residual waste treatment, or to non-optimal sorting and recycling processes, these are modelled to improve such that all collected waste is sent for recycling using best practice sorting and reprocessing processes. The best-practice yield rates are presented in Table A6.3.

Table A6.3: Assumptions for Best-Practice Yield Rates, %

Type of agri-plastic	Yield rate, %
Greenhouses	30%
Mulch film	67%
Small tunnels	50%
Stretch film	50%
Silages	50%
Non-woven nets	55%
Protective nets	18%
Bale net	100%
Irrigation pipe	25%
Drippers	25%
Twine	40%
Note: a 'yield rate' is the % of collected waste that is recycled, after accounting for losses in sorting and reprocessing facilities, and any direct disposal to residual waste facilities.	

Sources: Expert opinion estimated by CEDO – a large EU plastics recycler (see Table 3-1); Data provided by APE Europe

After accounting for recycling, the remaining collected waste (both soil and plastic 'losses') is split between landfill and incineration. The waste framework directive (as amended) states in Article 10(4) that:[502]

> *Member States shall take measures to ensure that waste that has been separately collected for preparing for reuse and recycling pursuant to Article 11(1) and Article 22 is not incinerated, with the exception of waste resulting from subsequent treatment operations of the separately collected waste for which incineration delivers the best environmental outcome in accordance with Article 4.*

Incineration does not deliver the best environmental outcome in terms of GHGs or air quality damage costs for residual disposal, and thus it is assumed that residual waste will be sent to landfill. We have therefore assumed that the proportion of residual waste (from separate collection schemes) that is sent to incineration will reduce over time in accordance with the requirements of this Article, with the goal of zero waste to incineration reached at the same time as best-performing collection rate targets are achieved (see Section A.6.2.2).

[502] Official Journal of the European Union (2008) *DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, 30th May 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0851&from=EN

A.7.0 Modelling Impacts of Policy Scenarios

A.7.1 Scenario Specification

The modelled scenarios are described in Section 8.0.

A.7.2 Agricultural Plastic Flow Modelling

Modelling of the quantity of agricultural plastics placed on the market, waste generated, collection rates and waste destinations proceeded using the methodology described in the below sections.

A.7.2.1 Placed on Market / Waste Generated

There is sparse data on which to base forward consumption trends even for a 'business as usual' (baseline) scenario (see Section A.6.2.1), and virtually no data to assess the likely impacts of e.g. the introduction of further EPR schemes on the consumption of agricultural plastics. Therefore, given the paucity of reliable data on which to base estimates we have assumed that projected consumption trends will not change (i.e. they remain the same as the baseline) for the policy scenarios modelled in this study.

A.7.2.2 Collection Rates

Expected collection rates are modelled in a similar fashion to the baseline. New EPR schemes are introduced in the 'implementation year' and the resulting impacts on collection rates are modelled to begin to take effect in the following year (i.e. if a scheme is introduced in 2023 then impacts are modelled from 2024 onwards). As for the baseline, collection rates are modelled to increase by an equal amount year on year, reaching the target collection rate in the 'target year'.

Modelled EPR schemes under the policy scenarios are assumed to cover the full range of plastic applications (most current schemes are only for a limited number of applications). Furthermore, it is assumed that existing EPR schemes, which are projected to continue into the future, will expand their scope in line with the comprehensive scope of newly implemented EPR schemes.

Finally, existing schemes are never switched from being mandatory to voluntary, i.e. if a voluntary EPR policy measure is modelled, any existing mandatory schemes will continue. The assumption remains that such schemes are modelled to expand their scope if they do not already cover the full range of plastic applications.

It is assumed that implementation of a mandatory EPR scheme will be faster than a voluntary scheme, because less time is required to on-board and negotiate with producers (all producers are required by legislation to participate). Furthermore, if there are legally binding collection and recycling targets in place, producers are likely to want to mobilise quickly to ensure the best chance of meeting these targets.

A.7.2.3 Waste Management Destinations

It is assumed that the relative proportions of plastic and soil in collected waste remain constant in the future. Whilst improvements in on-farm collection practises may reduce the quantity of soil collected the magnitude of such changes are unknown, and no targeted policies are modelled.

Losses at sorting facilities and reprocessors are modelled in a similar manner to the baseline (see Section A.6.2.3), that is, it is assumed that overall yield rates of collected waste within the scope of EPR schemes will increase (i.e. losses will decrease) year-on-year to reach best-practice rates. The timescale for this improvement in treatment methods is, as for the baseline, assumed to be equal to the period over which collection rates are increased. For modelling policy scenarios, the maximum yield rate is assumed to be met in the collection rate 'target year'.

The split of residual waste sent to incineration vs. landfill is modelled based on the same rationale as used for the baseline. I.e. it is assumed that waste collected within the scope of an EPR scheme and sent to residual treatment will gradually be diverted away from incineration, reaching zero waste to incineration in the same year as best-performing collection rate targets are achieved.

A scenario which stipulates bans on open burning in addition to the requirement to implement mandatory EPR schemes is modelled. For this scenario it is assumed that waste which was previously burnt is instead collected through national collection schemes, i.e. there is an increase in collection rate equivalent to the previous rate of open burning, and this increase is in addition to the gains in collection rate achieved through mandatory EPR schemes alone.

A.7.3 Economic Costs

A cost is incurred at the end-of-life of agricultural plastic for the collection and management of waste. Of course, farmers may also opt to partially or completely avoid this cost by opting for unwanted (and often illegal) disposal practices, such as open burning or dumping, or leaving plastic waste in the environment that can be collected. These disposal methods lead to poor environmental outcomes relative to management via well implemented national collection schemes.

In the absence of an EPR scheme, the cost of end-of-life management of waste falls solely to farmers, whilst the function of an EPR scheme is to divert some or all of this cost to producers. Producers may of course elect to 'pass on' some or all of the costs incurred through EPR fees to farmers by increasing the initial cost of products. Farmers are therefore more likely to properly dispose of waste if there is no additional cost at the end-of-life (or, if producer fees only partially cover the cost of waste management – as is commonly the case in existing schemes - a lower cost relative to the absence of an EPR scheme).

For the purpose of this study, a review of current EPR fees (incurred by producers) and collection costs (incurred by farmers) was conducted to understand the approximate net costs of waste management. Information on EPR producer fees for each material type (and any charges applied to farmers at the point of collection) was provided by stakeholders as outlined in Table A7.1.

Table A7.1: Data sources for cost of agri-plastic waste management

Source	Information provided
ADIVALOR	ADIVALOR EPR producer fees / farmer collection charges, by material type
AGRA (agricultural association in Andalusia)	Estimated costs of managing agri-plastics at EOL for Andalusian farmers, by material type (there is no EPR scheme in place in Andalusia)
APE UK	Estimated costs of managing agri-plastics at EOL for UK farmers, by material type (there is no EPR scheme in place in the UK)
Consorzio di Bacino Veronia	Estimated costs of managing agri-plastics at EOL for Italian farmers, by material type (there is no EPR scheme in place in Italy)
ECOFLER	Estimated costs of managing agri-plastics at EOL for Italian farmers, by material type (there is no EPR scheme in place in Italy)
ERDE	ERDE EPR producer fees / farmer collection charges Estimated cost of managing agri-plastics at EOL for German farmers not using the ERDE scheme
Green World Compounding	Estimated costs of managing agri-plastics at EOL for Spanish farmers, by material type (there is no EPR scheme in place in Spain)
IFFPG	Estimated cost of landfilling agri-plastics in Ireland IFFPG EPR producer fees / farmer collection charges
MAPLA	Estimated costs of managing agri-plastics at EOL for Spanish farmers, by material type (there is no EPR scheme in place in Spain)

The final costs compiled are representative of the average costs incurred by farmers and producers in existing EPR schemes (Table A7.2)

Table A7.2: Representative Costs to Farmers and Producers for Existing EPR Schemes in Europe

	End of Life Costs for Farmers, € per tonne collected	Producer Costs (EPR Fees), € per tonne placed on the market
Greenhouses	-	€ 30
Mulch film	€ 155	€ 240
Small tunnels	-	€ 120
Stretch film	€ 58	€ 72
Silages	€ 22	€ 67
Non-woven nets	-	€ 133
Protective nets	-	€ 133
Bale net	€ 93	€ 76
Irrigation pipe	-	€ 100
Drippers	-	€ 100
Twine	€ 1	€ 104

Note: Oxo / bio-degradable plastics are not collected and so are not included in the scope of EPR schemes / collection costs.

These sum of these costs, as a broad simplification, define the net cost of managing one tonne of waste. These net costs are distributed across farmers (as an end-of-life waste management fee) and producers (in the form of EPR fees) within the model, based on the following methodology:

- **Where no EPR scheme exists** – there are no EPR fees and so the full cost is placed on farmers
- **Existing and planned EPR schemes** – where an EPR scheme already exists or will be implemented in the baseline, the average costs as shown in Table A7.2 are applied.
- **For new EPR schemes** – for new EPR schemes introduced in modelled policy options (and existing schemes after the 'implementation' year), initially the costs as shown in Table A7.2 are applied. The proportion of end-of-life management costs paid by EPR fees (by producers) is then adjusted in line with the observed relationship between EPR fees and collection rates – i.e. EPR fees increase as the collection rate increases. This occurs as a consequence of an increase in the

tonnage of collected waste and therefore the quantity of waste for which producers are required to pay for the cost of collection/management. It is assumed that at very high collection rates, i.e. 95% as reached in the *mandatory EPR + participation requirement* measure, the full cost of waste management will be funded through EPR fees. EPR fees are then calculated for all time periods and scenarios based on the relative difference between the modelled collection rate and this 95% figure. A similar (but inverse) methodology is applied for the calculation of costs to farmers, i.e. costs to farmers decrease as collection rates increase, trending to zero at a 95% collection rate.

In order to compare the cost to agri-plastic producers of participating in an EPR scheme with the revenue they generate, we estimated the annual revenue generated by these producers in the EU (see Table A7.3). Note that this analysis is very high level; it is based on an extremely limited set of datapoints and intended to be indicative only.

Table A7.3: Estimated annual revenue of EU Agri-plastics market (2019) (excl. biodegradables / oxo-degradables)

Type of agri-plastic	Average sales price		Estimated annual sales in EU, 2019 (kt/year)	Estimates sales revenue, 2019 (€m)
	(€/tonne)	Source		
Greenhouses	€2,950	Armando Alverez Group	120	354
Mulch film	€2,055	Armando Alvarez Group, University of Turku, Polystar Plastics, Italian growers workshop	83	171
Small tunnels	€1,950	Armando Alverez Group	56	109
Stretch film	€2,552	Armando Alverez Group, IFFPG	146	373
Silages	€1,884	University of Turku, IFFPG	121	228
Non-woven nets	€6,546	Agrintech	8	52
Protective nets	€6,546	Agrintech	5	33

Bale net	€4,715	TAMA Europe, IFFPG	50	232
Irrigation pipe	€2,500	No data - estimate	20	50
Drippers	€2,500	No data - estimate	20	50
Twine	€1,800	TAMA Europe	80	144
Total				**1,799**
Note: Oxo / bio-degradable plastics are not included in the scope of EPR schemes and therefore are excluded from this analysis				

A.7.4 Environmental Impacts

Environmental impacts are presented in terms of the external costs of climate change and air quality impacts – the latter considering the impacts to human health. Data on the external costs of climate change impacts is derived from the Austrian Environment Agency Umweltbundesamt (UBA), whilst assumptions for the external costs of the air quality impacts are taken from analysis undertaken on behalf of the EEA.[503] Costs have been inflated to 2020 prices by applying deflators based on GDP (unit: chain-linked volumes) reported by Eurostat for Member States.[504]

Emissions associated with energy use are derived from the ecoinvent database for electricity and heat, whilst transport impacts are modelled based on the limits contained in the Euro standards.[505]

Impacts associated with product manufacture, recycling and residual treatment are included within the model. Impacts on product manufacture and recycling are derived from the ecoinvent database (for primary production)[506] and Gu et al for the energy used in recycling.[507] Energy data are used to calculate the other environmental impacts for recycling.

[503] Umweltbundesamt (2019) Methodological Convention 3.0 for the Assessment of Environmental Costs: Cost Rates; EEA (2011) Revealing the Cost of Air Pollution from Industrial Facilities in Europe

[504] Eurostat (2020) GDP and main components (output, expenditure and income) [nama_10_gdp], Accessed 24th September 2020, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp&lang=en

[505] Ecoinvent database available from https://www.ecoinvent.org/ ; transport emissions data available via https://dieselnet.com/

[506] Ecoinvent database available from https://www.ecoinvent.org/

[507] Gu F, Guo J, Zhang W, Summers P and Hall P (2017) From waste plastics to industrial raw materials: A life cycle assessment of mechanical plastic recycling practice based on a real-world case study, *Science of the Total Environment*, 601-602, pp1192-1207

Emissions from residual treatment are derived from Eunomia's in-house treatment model, which is the source of information used to derive the environmental impacts of these systems within the European Reference Model on Waste.[508]

Impacts are also considered for open burning; in this case, no energy-related benefits are assumed to occur. The impacts on climate change are also derived from Eunomia's in-house treatment model. Data on the air quality impacts of this practice comes from various sources.[509]

The impact assessment includes consideration of the black carbon emissions which are assumed to contribute to the climate change impacts. Key sources of data for this part of the modelling are Bond et al – which provides data on the global warming potential of black carbon - and Reyna-Bensusan et al who provided the data on the emissions of black carbon for different types of material from open burning.[510]

[508] Eunomia / CRI (2014) Development of a Modelling Tool on Waste Generation and Management Appendix 6 Environmental Modelling, Report for DG Environment

[509] Cory Riverside Energy (2018) Environmental Impact Assessment: Appendix E BAT Assessment; Liptak B (1991) Municipal Waste Disposal in the 1990s; Park Y, Kim W and Jo Y (2013) Release of Harmful Air Pollutants from Open Burning of Domestic Municipal Solid Wastes in a Metropolitan Area of Korea, *Aerosol and Air Quality Research*, 13, pp1365-1372

[510] Bond et al (2013) Bounding the role of Black Carbon in the Climate System: A Scientific Assessment, *Journal of Geophysical Research: Atmospheres*, 118, pp5380-5552; Reyna-Benson N, Wilson D, Davy P, Fuller G, Fowler G and Smith S (2019) Experimental measurements of Black Carbon Emission Factors to estimate the Global Impact of Uncontrolled Burning of Waste, *Atmospheric Environment*, 213, pp629-639

A.8.0 Rejected Policy Measures

The following policy measures were rejected following the initial screening process, in line with Tool #17 of the Better Regulation Toolbox.

Leasing model for greenhouse films

Greenhouse film has an average useable life of 3 to 4 years. Overexposure to intense sun can lead to the degradation of this plastic, affecting its recyclability. This policy measure is introducing a leasing model so that greenhouse films are removed at the optimum time (a balance between when film properties are still beneficial for growing crops and when film properties are negatively affecting potential for recycling).

The measure was screened out on the basis of **effectiveness and efficiency**. Further research indicated that if greenhouse films are not changed every few years, crop growth efficiency and profitability is reduced. There is therefore already a strong incentive for farmers to replace greenhouse films before they degrade past a certain threshold. Greenhouse films also have a positive value to recyclers, with farmers receiving a payment in some circumstances for its delivery to a collection point. The additional benefits of a leasing model are therefore likely to be low.

Tax on virgin plastic production

A tax on virgin plastic production would increase the cost of using virgin plastic in the production of agri-plastics, thus incentivising the use of recycled content. This measure was screened out on the basis of **proportionality**. A tax on virgin plastic production would apply to a much broader range of materials than agri-plastics.

Incineration ban or tax

Article 10 (4) of the WFD states that separately collected waste should not be incinerated. A ban on the incineration of separately collected agri-plastics is therefore already in place.

Landfill ban or tax

A landfill ban on agri-plastics would not serve to incentivise increased levels of collection. While it would limit the residual treatment option to energy recovery, a switch from landfill to incineration would not be beneficial from a GHG perspective. While increasing the cost of disposal (through a landfill tax) may make recycling of some agri-plastics more financially attractive, it would not be as effective as establishing EPR schemes with collection and recycling targets

Make EN 17033 mandatory for all BDMs through new legislation

This policy measure introduces legislation to ensure that only biodegradable mulch films that are certified to EN 17033 are placed on the market (and therefore, ensures that all mulch films which claim to be biodegradable, actually are biodegradable). This measure was screened out on the basis of **proportionality**. It was deemed to be politically unfeasible to introduce a new piece of legislation specifically for this purpose, especially when given other policy measures which aim to achieve the same outcome, but which do not involve a new piece of legislation are available.

Encourage the use of alternative materials for greenhouses

For some agri-plastics, especially greenhouses, there are alternative materials that can be used (e.g. permanent steel / glass structures). A policy measure to encourage the use of alternative materials for greenhouses was screened out on the basis that collection and recycling rates for plastic greenhouses are already relatively high (greenhouse plastic has a value to recyclers, and therefore there is a financial incentive for its separate collection).

Exchanges of best practices and education of professionals

It is important that farmers are aware of the environmental implications of failing to manage agri-plastics appropriately at their end-of-life. They should also be aware of the best practices for reducing contamination during the removal and storage process. Implementing this as a standalone measure was screened out on the basis of **relevance**; it makes more logical sense to disseminate this information as part of an EPR scheme (one of the other proposed policy measures).

Recycled content targets

Recycled content targets could be placed on agri-plastics, however, such a policy would not necessarily stimulate demand for *agri-plastic* recyclate (the recycled content could be sourced from other types of plastic) and therefore may not significantly increase the demand for agri-plastic recyclate as intended. This measure was screened out on the basis of **effectiveness and efficiency**. Instead, it is proposed that under an agri-plastics EPR scheme, recycled content could be an appropriate criteria for modulation.

A.9.0 Agri-plastic EPR Schemes

Extended Producer Responsibility (EPR), is defined by the OECD as:[511]

> *'An environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle'.*

Accordingly, EPR has the potential to be aligned with the polluter pays principle, which is enshrined in EU Law. Article 191(2) of the Treaty on the Functioning of the European Union (TFEU) states that:[1]

> *"Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive*

[511] OECD (2001) Extended Producer Responsibility: A Guidance Manual for Governments
[1] OJEU (2012) Consolidated Version of The Treaty on the Functioning of the European Union, Official Journal of the European Union, 26th October 2012, available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:12012E/TXT&from=EN

action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."[512]

A number of examples of approaches to extended producer responsibility for agri-plastics are in place in Member States and other countries beyond the EU. Given that EPR schemes can take a number of forms, exhibiting different design features, and providing different levels of performance, it is important to understand the characteristics of a well performing scheme. In the following sections we review some of the pertinent aspects of existing schemes in order to draw out key design principles. In so doing we consider the relative merits of voluntary and mandatory approaches to EPR, and note the inherent challenges in seeking high collection rates within voluntary schemes.

A.9.1 Key Design Principles

A.9.1.1 Extent of Overall Cost Coverage

Under EPR, in principle, producer fees should cover the full net costs of managing the product at EOL (i.e. the cost of collection, transport and treatment), and these costs should be covered up-front. The extent to which this occurs in existing schemes is examined in Table A9.1.

Table A9.1: Extent of Overall Cost Coverage[513]

Scheme	Extent of Overall Cost Coverage
ADIVALOR	For most product types, the producer fee does reflect the full net costs of EOL management. Mulch films / flat sheets are an exception; the producer fee is not set at a level that reflects true EOL costs due to concerns that this could make the risk of free-riding too high. To make up the shortfall in funding, farmers must make a contribution of €155 per tonne of mulch film / flat sheeting at the point of collection (a discount is applied if the farmer can prove via scientific analysis that the contamination rate is <50%).[514] The scheme is gradually increasing the producer fee for mulch film / flat sheeting over time, with the objective of covering the full net costs of EOL up front (see Figure A9.1).

[512] Emphasis added
[513] Interviews with ADIVALOR, ERDE, IFFPG and SvepRetur
[514] In 2020, the discount is between €105 per tonne and €60 per tonne depending on the material.

Scheme	Extent of Overall Cost Coverage
ERDE	Producer fees are used to pay an incentive to independent, ERDE accredited, collection points for every tonne of eligible agri-plastics they collect and recycle. It is estimated that these producer fees cover ~30 – 40% of end of life costs for silage films and bale nets. The remaining 60 -70% of costs are made up by fees charged to farmers at the collection points. These fees are set independently by the collection points and therefore can vary (in some cases collection points see take back of films as part of their service and assume the costs).
SvepRetur	Producers collect a levy from farmers when they invoice for sales of agri-plastics. The accumulated levies are sent to SvepRetur twice a year. This levy funds the administration of SvepRetur and covers the cost of the collection contractor. The contractor retains ownership of the agri-plastic once it is collected and is responsible for its EOL treatment. Farmers are not charged at the point of collection.
IFFPG	Producers pay a flat fee of €140 per tonne of agri-plastics placed on the market. It is estimated that producer funding covers ~70% of IFFPG's costs (administration, marketing, collection, transport, recycling etc.). The remaining 30% of costs are made up by farmers, who are charged €40 per tonne of silage wrap /sheeting at a bring centre and €90 per tonne for a farmyard collection; and €5 per half tonne bag of netting & twine.[515]

As demonstrated in Table A9.1, in existing agri-plastic EPR schemes, producer fees do not always fully cover the net EOL costs up front. In some cases, farmers have to supplement producer fees with a weight-based contribution at the point of collection. The main drivers behind this are:

1) The desire to avoid producer fees being high enough to dissuade producers from participating in the scheme (this is an issue specific to voluntary schemes, because in mandatory schemes producers cannot choose to not participate). By sharing the EOL costs between producers and farmers, this risk can be reduced.
    - It is worth noting that in the case of agri-plastics, full net costs can be equivalent to a significant percentage of the product value. For example, IFFPG estimates that the producer levy of €140 per tonne represents approximated 4 – 5% of the retail price for silage wrap, while ADIVALOR estimates that the producer levy can be up to 10% of the product retail

[515] *FAQ*, accessed 4 May 2020, https://www.farmplastics.ie/faq/

value (i.e. in the case of mulch films).[516,517] In comparison, for packaging EPR schemes full net costs are typically much lower relative to the value of the item (product + packaging) purchased by the consumer. Agri-plastic producers may therefore be particularly sensitive to the magnitude of producer fees.

2) A weight-based fee at the point of collection acts as an incentive for farmers to reduce contamination, and therefore reduce the transport / treatment costs associated with managing the products at their EOL. This is the case in both voluntary and mandatory schemes.

Despite the reasoning behind farmers having to pay a fee at the point of collection, the concept does not align with a core design principle of EPR schemes – that producers bear the costs of managing products at their EOL, and that this cost is covered up front. There is a risk that charges at the point of collection could act as a financial disincentive for farmers to return their agri-plastics via the scheme, possibly encouraging mismanagement (e.g. burning agri-plastics on site).

An alternative worth exploring is whether a rebate-style system could be implemented whereby the cost of an assumed level of contamination is included in the producer fee, and farmers receive a rebate if they deliver plastics with a contamination rate below that threshold. This mechanism does not require farmers to pay any fee at the point of collection, and in fact could incentivise farmer participation (as the farmer has a chance of receiving a rebate if they return their plastics with a low level of contamination). The complication is that it is very difficult to visually assess the rate of contamination of any agri-plastics (e.g. film heavily contaminated with moisture would appear clean) so some level of scientific analysis would be required, at an additional cost. ADIVALOR overcomes this challenge by placing the onus on farmers to request a scientific analysis if they believe their agri-plastics to be below the contamination threshold. If the results show this is the case, the EPR scheme covers the cost of the analysis (and provides the rebate), but if not, then farmers are liable for the cost of the analysis.

A.9.1.2 Allocation of Costs By Agri-plastic Product Type

In principle, producer fees should vary by product type to reflect the variation in EOL costs (for example, managing mulch film at its EOL is far more expensive than managing greenhouse film). This is a fair approach that avoids producers who sell one type of agri-plastic subsiding the cost of managing other types of agri-plastics. The approaches taken in existing schemes are detailed in Table A9.2.

[516] Interview with IFFPG
[517] Interview with ADIVALOR

Table A9.2: Producer Fee Variation by Product Type[518]

Scheme	Fee
ADIVALOR	Producer fees vary by product type to reflect EOL costs. 2020 fees range from €80 per tonne for greenhouses and tunnels to €240 per tonne for mulch film (see Figure A9.1 for more detail). Note that the mulch film producer fees do not reflect full EOL costs – farmers are also required to make a €155 per tonne contribution at the point of collection.
ERDE	Producer fees vary by product category to reflect different EOL costs. Currently there are two categories: 1) silage film & silage stretch and 2) bale nets.
SvepRetur	Producer fees vary by product type to reflect EOL costs.[519]
IFFPG	Producer fees do not vary by product type. There is currently a flat levy of €140 per tonne for silage wrap, silage sheets, netting and twine. IFFPG is considering introducing a range of fee levels to reflect EOL costs in the future.

Figure A9.1: ADIVALOR – Producer Fees (2018 – 2022)

Source: ADIVALOR

In most cases, existing schemes do vary producer fees by product type to reflect different EOL costs and avoid cross-subsidisation. It is interesting that the Irish scheme,

[518] Interviews with ADIVALOR, ERDE, IFFPG and SvepRetur
[519] Full list of 2020 fees is available here: http://svepretur.se/wp-content/uploads/Recycling-fees-2020-3.pdf

which is the closest to a mandatory approach, is the one scheme that does not vary producer fees by product category.[520] This is despite netting and twine costing considerably more to manage at EOL than silage wrap and sheeting (netting and twine is currently incinerated as the scheme is unable to find recycling offtakers). The Farm Plastics Regulations were only amended to include netting and twine producers in 2017; it was considered a 'hard sell' to bring netting and twine producers in at a higher producer levy rate than that which applied to silage wrap and sheeting producers. Also, currently, only around ~18% of netting and twine placed on the market is collected by the IFFPG scheme, so there is sufficient income from the producer levy and farmer collection charges (€5 per half tonne bag) to fund the EOL costs of the collected material. As collection rates grow, IFFPG plans to revisit the funding model for the netting and twine waste stream and is considering introducing a more granulated fee structure in the future.[521]

A.9.1.3 Extent of Producer Participation

EPR schemes should aim for 100% producer participation. Higher levels of participation would appear to be more likely under a mandatory approach than under a voluntary approach. High levels of producer participation, by definition, reduce the number of free-riders (although free-riding through under-declaring what is placed on the market remains a possibility). High levels of participation also help to enable high quality data collection (see Section A.9.1.5). The level of producer participation in existing schemes is outlined in Table A9.3.

Table A9.3: Producer Participation[522]

Scheme	Extent of producer participation
ADIVALOR	ADIVALOR estimates that 98% of the tonnes of agri-plastics placed on the market in France are covered by the scheme. It is not known how producer participation rates have evolved over time.
ERDE	ERDE estimates that 85 – 95% of producers of stretch film / silage[523] in Germany are part of the scheme. It took a few years to build up this level of participation; the scheme started with 4 producers and is now at 50.

[520] Under the Farm Plastics Regulations a producer of the specified farm plastics must become directly involved in the recovery of farm plastics waste from customers through offering a deposit and refund scheme, or participate in the collection / recovery scheme run by IFFPG. Currently all producers opt to participate in the IFFPG scheme.
[521] Interview with IFFPG
[522] Interviews with ADIVALOR, ERDE, SvepRetur and IFFPG
[523] Stretch film / silage are the major agri-plastic products managed by the scheme.

Scheme	Extent of producer participation
SvepRetur	SvepRetur estimates that it has close to 100% producer participation, and has done since the scheme inception in 2002 (all of the large players on the Swedish market were involved in the establishment of the system).
IFFPG	Producers must participate in the IFFPG scheme unless they choose to offer a DRS scheme to their customers. Currently, no producers have opted for the DRS option. It is estimated that the compliance rate hovers between 90-95% (most non-compliance occurs in the border counties when product is brought down from Northern Ireland and sold without a levy).

Existing agri-plastic EPR schemes appear to achieve high participation rates. This is to be expected from the 'mandatory' Irish scheme, because all producers must participate by law (if they do not offer a DRS scheme), and monitoring and enforcement is in place to ensure this. In comparison, the high producer participation rates achieved by voluntary schemes are likely to be at least in part linked to the threat of legislative enforcement by the government if the voluntary approach fails. All of the voluntary schemes have made agreements with government to achieve particular collection/recycling rate targets:

- ADIVALOR has a framework agreement with the French Government, which includes recycling rate targets (Of material collected: 84% for plastic films; 50% for nets and twines);
- ERDE has a voluntary commitment to increase the collection rate of silage and stretch films to 50% by 2021 and 65% by 2022 (all silage and stretch films collected are recycled).[524]
- SvepRetur has a target to collect 70% of agri-plastics and to recycle at least 30% of what is collected.

It is not known how a voluntary scheme without such targets, and without the threat of legislative enforcement if they are not met, would perform in terms of producer participation.

The challenge of achieving 100% producer participation rates under a voluntary scheme is likely to increase as the scheme seeks to achieve higher collection rates (and indeed higher recycling rates). This is because as collection rates increase, there is a diminishing proportion of products placed on the market for which a levy is paid but the product is uncollected and incurs zero cost to the scheme. These levies essentially subsidise the EOL costs for the material that is returned via the scheme, and so as collection rates rise, producer fees are likely to rise to become closer in line with true EOL costs.

A high level of producer participation is important because it minimises the risk of free-riders. The risk of free-riders is potentially significant in agri-plastic EPR schemes,

[524] https://www.plasteurope.com/news/AGRICULTURAL_FILMS_RECYCLING_t242812/

because once an agri-plastic product has been purchased and used, it is often not possible to identify which producer it came from, and therefore whether or not a levy has been paid. This heightens the risk that products placed on the market without a levy are returned via scheme collection points.

Other voluntary EPR schemes, such as the PAMIRA scheme for pesticide and fertiliser packaging in Germany, have addressed the issue of free-riding by including a logo on all packaging from participating producers: only packaging displaying this logo is accepted at collection points. However, this is not necessarily a solution for agri-plastics, particularly for films, nets and twines, where affixing a logo that will be easily identifiable after use is impractical. IFFPG takes a different approach: farmers receive a 6-digit code when they purchase levied plastics, which entitles them to a significant reduction in collection fees. Farmers therefore have an incentive to avoid purchasing non-levied plastic from across the border in Northern Ireland.

A.9.1.4 Extent of farmer participation

An agri-plastics EPR scheme should ideally achieve 100% participation from farmers. In Table A9.4, the estimated farmer participation rates and also the collection rates of existing schemes are compared.

Table A9.4: Collection rates[525]

Scheme	Farmer Participation	Collection rates
ADIVALOR	Unknown – assumed to be relatively high.	Average collection rate was 67% in 2019. Collection rates by product type were as follows: • Agricultural films: 77% • Bale nets & twine: 41% • Anti-hail nets: 31% • Irrigation flexible pipes: 76%
ERDE	ERDE does not collect data on the % of total farmers participating in the scheme.	The collection rate of stretch and silage film was ~37% in 2019.
SvepRetur	SvepRetur estimates that at least 95% of farmers participate in the scheme.	SvepRetur estimates that, in 2018, ~92.5% of the total agri-plastics (including packaging) placed on the Swedish market were collected.

[525] Interview with ADIVALOR, ERDE, SvepRetur and IFFPG

Scheme	Farmer Participation	Collection rates
IFFPG	IFFPG estimates that 65 – 70% of livestock farmers in Ireland use the scheme (each individual farmer does not necessarily use it every year, but will participate when enough plastics are stockpiled). There are a couple of independent collectors who operate separately to the IFFPG scheme, which non-participating farmers may use.	2019 collection rates by product type were as follows: • Silage wrap and sheeting: 79% • Netting and twine: 18%

There are some EPR design features which may increase the likelihood of full participation from farmers:

- Ensuring full net costs are covered up front in the producer fee, so that farmers are not required to make a financial contribution at the point of collection.
- Requiring mandatory participation from farmers under law. None of the schemes currently operating require mandatory farmer participation – farmers have a choice to use an alternative EOL solution (for example, using private waste managers who may landfill or incinerate the plastics).

A.9.1.5 Quality of Data

Comprehensive collection of high quality data that can be subject to external verification is required to effectively monitor and evaluate EPR scheme performance. Details on the approach to data collection and management in existing EPR schemes are outlined in Table A9.5.

Table A9.5: Approach to data collection and management

Scheme	Approach to data collection and management
ADIVALOR	Unknown

Scheme	Approach to data collection and management
ERDE	ERDE collects the following data: a) The amount of product placed on the German market by members of ERDE: This data is collected by a trustee (in ERDE's case a tax auditor) who is obligated to treat all data confidentially. b) The amount of product collected and recycled: All collection points have to send in their collected quantities to RIGK together with corresponding documentation. The documentation includes all weighing notes of the EOL-process and a recycling declaration by the final recycling plant. ERDE only accepts the documentation when the collection and recycling took place in a European plant known and audited by RIGK. The incentive to the ERDE collection points is only paid if the documentation is correct and complete.
SvepRetur	SvepRetur collects the following data: • The amount of product placed on the Swedish market by SvepRetur members: Producers declare what product / quantity they have sold every quarter via an online portal. • The amount of product collected: The collector company provides weight / freight documentation. • The amount of product recycled: Data collected from recycling plant Data is verified by random visits to declarants to check their book keeping. SvepRetur also monitors data for any surprising patterns.
IFFPG	IFFPG collects detailed information in relation to the agri-plastics market in Ireland. This is achieved by requiring producers to attach a unique label code to each pallet of products that they place on the market. This label code passes down the supply chain to farmers. When farmers present the label code at collections, they qualify for a lower collection charge. All producers in Ireland are members of IFFPG, so IFFPG can be confident that it has a full view of the products being placed on the market and returned via the scheme. In relation to farmers, IFFPG can identify the product they have purchased, and it could also identify the volume of product they purchased if necessary. IFFPG can also identify the counties where farmer service uptake is relatively low by comparing the number of customers in that county with the number of livestock farmers listed by the Central Statistics Office. It can use this information to target farmers in these areas through extra advertising and more frequent / weekend bring-centres.

As a minimum, for each main product type, the following data should be collected to allow collection rates and recycling rates to be calculated, and progress against targets assessed:

- tonnes placed on the market;
- tonnes collected;
- tonnes recycled.

Under a voluntary EPR scheme, only participating producers are obliged to declare the tonnes of agri-plastics placed on the market. So unless there is participation from all producers, there is a risk of underestimating (or overestimating) the tonnes placed on the market, and therefore miscalculating the collection rate. This risk is minimised under a mandatory scheme, where all producers must participate.

More detailed data collection, as occurs in the Irish scheme, is preferable. Ideally, there should be a way of logging the volume and type of agri-plastic products sold to each farm and the volume and type of agri-plastic products returned by each farm (a mass-balance approach). This level of insight would allow the EPR scheme operator to spot patterns in the data and identify where farmers appear to not participate in the scheme. This data could potentially support other policy measures (e.g. a requirement for farmers to participate in an agricultural plastics collection scheme or a ban on burning of agricultural plastics).

A.9.1.6 EPR Design Summary

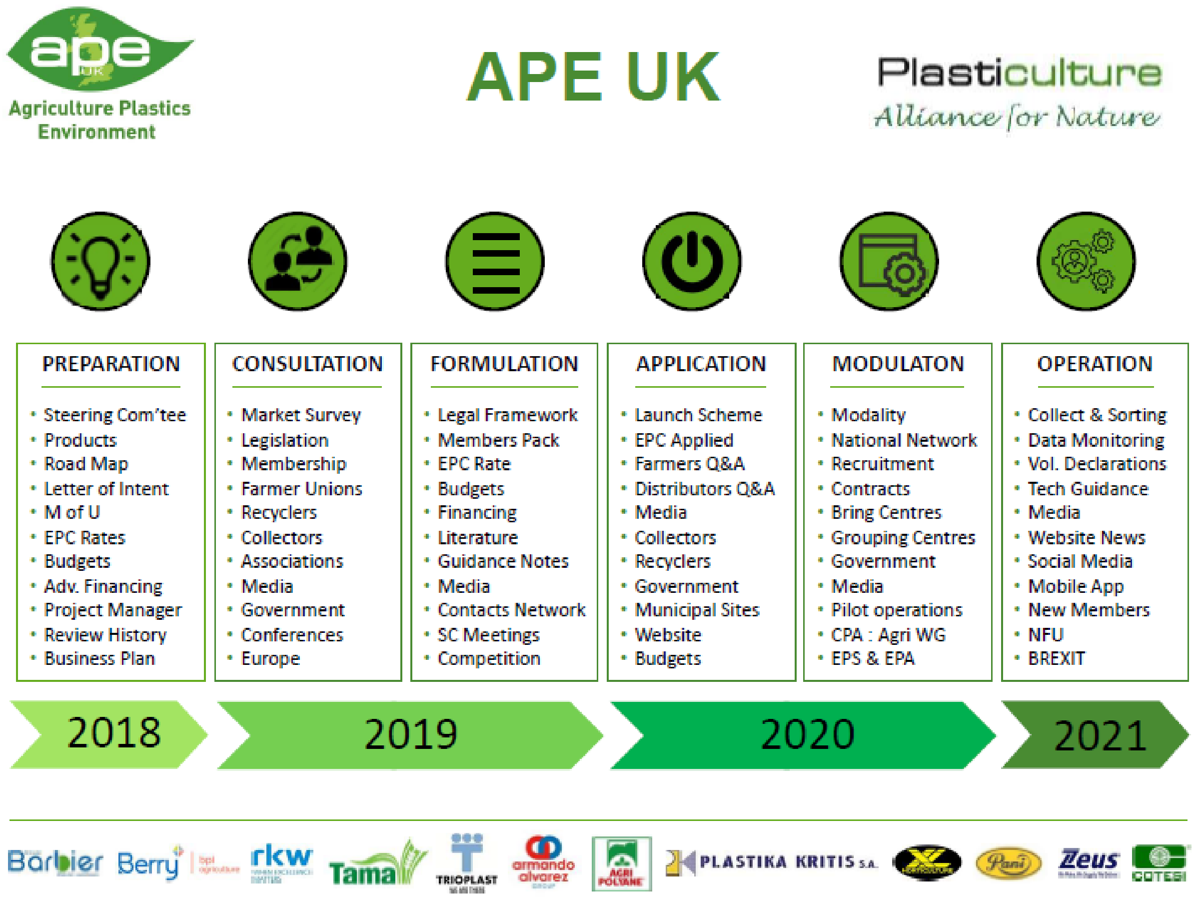
In summary, there are a number of key design principles that a best-practice agri-plastic EPR scheme should aim to achieve / incorporate:

- Producer fees should cover the full net costs of managing the product at EOL (i.e. the cost of collection, transport and treatment), and these costs should be covered up front. This should avoid the need for a supplementary charge at the point of collection, which may discourage farmer participation in the scheme.
- In the absence of weight-based collection charges, another method is required to incentivise farmers to reduce contamination. This could be a rebate-style system where the costs of an assumed level of contamination are incorporated in the up-front producer fee, and farmers receive a partial rebate if they deliver agri-plastics with contamination levels below the threshold.
- Producer fees should vary by product type to reflect the variation in EOL costs between different agri-plastics. There should be no cross-subsidisation.
- The EPR scheme should aim for 100% producer participation. High levels of producer participation are essential for supporting high collection rates, minimising the risk of free riders (a particular risk with agri-plastic EPR schemes), and obtaining accurate data on the volume of products placed on the market.
- The EPR scheme should aim for 100% farmer participation.
- Comprehensive, high quality and verified data collection. Ideally, a system should be in place so that the volume and type of agri-plastics sold to each farm, and the volume and type of agri-plastics returned by each farm, can be tracked.

A.9.2 EPR Scheme Implementation Timescales

According to APE Europe, a period of 3 to 5 years is necessary to implement a mature agri-plastics EPR scheme with full product and territory coverage. Figure A9.2 provides a summary of the key stages involved in the process – from preparation to operation. This example is specifically referencing the set-up of a voluntary EPR scheme in the UK.

Figure A9.2 ADIVALOR – Producer Fees (2018 – 2022)



A key element of the implementation process is engagement with stakeholders (producers, traders, co-operatives) to gather support for the scheme. This is particularly important for voluntary schemes, which cannot operate successfully without a certain level of support from producers. As a rough guide, APE UK suggests that the threshold at which a national EPR scheme for agri-plastics can be launched is when at least 80% of the products placed on the market are covered by participating producers (any lower than that and the risk of competitive distortion in the market is too high). Previous attempts to launch a voluntary agri-plastics EPR scheme in the UK have failed because not enough producers were committed.[526] It is worth noting that the major producers of agri-plastics are the same in most member states, so, over time, the launch process of

[526] Interview with APE UK

new national schemes can be expected to become smoother, as producers become more familiar and accepting of these types of schemes.