Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy

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Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy

Final Report

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Abstract

In 2015 the Commission adopted an EU action plan for the Circular Economy to help stimulate Europe's transition towards a circular economy. The growing number of plastic products and packaging marketed as 'biodegradable' or '(home) compostable' raises the question of the extent to which biodegradability and (home) compostability of plastic is beneficial in the context of the transition towards a circular economy. This study assesses possible implications of the use of such products and identifies conditions/applications in which industrial or home compostability of products or packaging could be of added value when compared to reuse and other forms of recovery.

The results indicate that the evidence is weak in favour of any particular agronomic benefit associated with compostable plastic material in compost or digestate and therefore material choices for products and packaging should prioritise recyclability over compostability. Exceptions to this are where the use of compostable plastic have proven 'added benefits' such as increasing the collection of organic waste and its diversion from residual waste or reduction in plastic contamination of compost. Industrial composting and anaerobic digestion infrastructure differ considerably across the EU and effectiveness at treating compostable plastic varies even if materials comply with harmonised standard EN 13432 on requirements for packaging recoverable through composting and biodegradation. Resulting undegraded compostable plastic residues is a significant risk that cannot be quantified at present.

Executive Summary

The Biodegradable Plastics Market

The global production capacity for all biodegradable plastics in 2016 was reported to be 964,000 tonnes and it is estimated that 175,000-200,000 tonnes was produced for the European market in 2016 with around half of all the biodegradable plastic products in the EU being sold in Italy. This means that biodegradable plastics make up approximately 0.6% of the total (35 million tonnes) plastics market in Europe for products in scope of this study.

The key applications are carrier bags and biowaste bags, which combined make up almost 60% of the certified product market by number of certifications in 2019, and 68% of the mass of biodegradable plastics product found on the market in 2015. Other flexible packaging, rigid packaging and single use items such as trays, cups and cutlery range from 2 to 12% of the market.

The global biodegradable plastics market is currently dominated by three different groups of polymers; polyesters, PLA and starch blends. These polymers hold approximately 27%, 24% and 42% of the market respectively.

Nature and Quality of Compost Resulting from Compostable Plastics

Direct evidence of ecological improvement from compostable plastics is sparse and inconclusive. There appears to be consensus around the lack of nutritional benefit and therefore this leads towards investigating more in-depth the potential physical benefits of incorporating carbon directly into the soil as biomass. However, the evidence for the extent to which assimilation of the carbon into the compost takes place is also limited. Only recently has the carbon in the polymer been tracked into biomass, but this is difficult to quantify at this stage. Existing research suggests that at least half of compostable plastic is 'lost' to CO2 air emissions as it biodegrades in composting. The remaining material is incorporated into biomass in the compost. Given scarce evidence further research is required.

This study explores the types of organic waste infrastructure that exists in Europe and the implications of processing compostable plastics within these systems. **Anaerobic digestion** (**AD)** is increasingly considered the preferred method for processing food waste from an environmental perspective. The acceptability of compostable plastics at AD sites varies depending on the operational scheme of the site which varies, even within countries. With regard to incomplete biodegradation, several stakeholders report this happening in AD and composting plants, with the problem being more pronounced in AD plants. The same issues have been highlighted in several countries.

In-vessel Composting (IVC) is a controlled composting process exposed to oxygen rather than a digestion process in the absence of oxygen. Some sites have primary screens that may send plastics and compostable plastics into rejects. This is a common practice in Germany where conventional plastic bags—which are often used by households to deliver biowaste—are removed. **Germany also uses 'fresh compost' which is typically applied directly to agricultural land but can be composted for as little as 6-8 weeks which is typically not enough time for biodegradation of compostable plastics to fully occur.** Conversely, Italy has a general minimum requirement that compost should be matured for at least 90 days, which is in line with assumptions on which the requirements in the Standard EN 13432 (for treatment in aerobic conditions) appear to be based.

Importantly, **none of the Member State or EU level Regulations on compost or digestate quality (resulting from any of the above processes) take into account the impacts of microplastics on the terrestrial environment or seeks to reduce these.** Currently plastic contaminants under 2mm in size is allowable, which is larger than the definition of microplastics (typically <1mm). This is potentially problematic for all types of plastic, but in the context of this report, incomplete biodegradation or fragmentation may create plastic particles that fall below these limit values and are therefore not targeted for removal.

Effects of Contamination of Plastics Separately Collected for Material Recycling

With regard to compostable plastics in conventional mechanical plastics recycling, reports indicate that the final levels of contamination are acceptable to subsequent recycling processes. **However, this refers to a scenario in which compostable plastics are only used in very small quantities in niche applications**. More widespread use in packaging, particularly if more rigid packaging is used, may require adaptation of the sorting lines, or generate levels of contamination that may cause problems for mechanical recycling. In Italy, where there is already widespread use of compostable plastics (with a concentration relative to conventional plastics of at least five times greater than any other EU country) the overall contamination rate is below the levels considered to be of concern for mechanical recycling before sorting.

Environmental Performance of Alternative Non-plastic Biodegradable Products Compared with Compostable Plastic

Non-plastic biodegradable alternative products such as paper can be used to fulfil the same function as compostable plastics. However, there is limited literature comparing compostable plastic products to non-plastic biodegradable products.

Three carrier bag studies show different results when comparing paper and compostable plastic carrier bags. Two out of the three studies find that the compostable plastic bag has generally lower or very similar environmental burdens compared to a paper bag, however the overall assumptions of the studies, including how reuse is incorporated has a greater bearing on the result overall.

Another study on packaging film was generally inconclusive as some environmental impact categories showed the non-plastic alternative has a lower environmental impact and in other impact categories the compostable plastic performs better therefore it is difficult to draw specific conclusions and there appears to be **no clear evidence that non-plastic biodegradable alternatives are environmentally preferable to compostable plastics.**

The main take away points are; compared to production, **the end of life stage often has low contribution to the overall impacts** but that **landfilling of compostable plastics should be avoided** in order to reduce climate change impacts from methane release**.** In regards to the production side, **feedstock and energy use have the largest influence and, bio-based, compostable products can offer benefits in some impact categories,** especially climate change, but show higher impacts in other categories compared to fossil-based plastics considering an average EU end of life treatment.

The Risk of Littering Biodegradable Plastics

There is a lack of recent conclusive empirical evidence that clearly correlates the marketing of plastics packaging or products as biodegradable/compostable with an increase in the tendency to litter these - further research is needed. However, several studies point towards **a perception amongst consumers that 'biodegradable' or 'compostable' is an inherently virtuous aspect** of a product and that littering such an item would be less impactful. There is also **evidence suggesting that perceptions of the time for such plastics to biodegrade are not likely to be in line with reality.**

Reviewing Standards for Industrial Compostability - EN 13432

There are currently two harmonised standards for biodegradation in industrial composting and anaerobic digestion: EN 13432 has been in place since 2000 and is linked to the European Directive on Packaging and Packaging Waste (94/62/EC) where meeting the standard presumes conformity with the essential requirements in the Directive. EN 14995 contains identical criteria, but its scope is for other non-packaging plastic products. Through the research conducted for this report, two main criticisms of the standards have been identified:

- **The aerobic biodegradation and disintegration test durations are too long.**
- **The assumptions in the anaerobic biodegradation test do not reflect reality.**

It is recommended that the standard EN 13432 (and consequently EN 14995) be updated to reflect the latest scientific understanding and approaches. This includes a requirement to **separately test and meet the criteria for biodegradation of all organic constituents** which are present in the material at a concentration between 1% and 15% and to **introduce a nitrification inhibition test and an earthworm toxicity test.** There **may be merit in introducing a test to validate the biodegradation performance in soil**

There are also several other potential weaknesses—particularly around the testing time threshold and how this relates to reality. I**t is recommended that Member States conduct their own trials to determine whether the Standard is fit for the purpose** of verifying that compostable plastics perform as required (noting that 'performance' is a relative term that will be dictated by the local process and compost quality requirements). This will help in determining whether they should accept compostable plastics or not in their biowaste treatment facilities.

Criteria in Which the Use of Compostable Products and Packaging Could Be Beneficial

Based the preceding findings the following points summarise the basis for the criteria setting:

- At this stage the evidence is weak in favour of any particular agronomic benefit associated with compostable plastic material in compost or digestate. Some carbon from the biodegradable plastics appears to be incorporated into the biomass but at least half is 'lost' to CO_2 air emissions. This leads to the conclusion that material choices for products and packaging should prioritise recyclability over compostability.
- Exceptions to this are where the use of compostable plastic have proven 'added benefits' such as increasing the collection of organic waste and its diversion from residual waste or helping to reduce plastic contamination of compost, thus facilitating circularity in the bioeconomy.
- Industrial composting and anaerobic digestion infrastructure as well as organic waste collection practices differ considerably across the EU and are not all effective at treating compostable plastic.
- Material compliance with EN 14432 does not automatically lead to effective treatment of compostable plastics and the Standard may require amending to increase its relevant and effectiveness.
- Undegraded compostable plastic residues in compost or digestate is a significant risk that cannot be quantified at present. This is not mitigated under fertiliser quality protocols at Member State or EU level (Fertiliser Regulation) which currently do not require the absence of microplastics (<2mm).

It is appropriate to define the prerequisites that need to be achieved for the disposal of compostable packaging alongside biowaste to be considered an option. This is in order to make sure that;

- the organic waste treatment infrastructure is capable of dealing with these materials/products with no negative effects;
- the material/product performs as expected in industrial composting; and,
- the waste treatment method and the appropriate disposal actions required by the end user to facilitate this is effectively communicated.

Without these three elements above in place, the likelihood of negative consequences is high i.e. consumer confusion leading to improper disposal and/or situations where organic waste treatment is hampered. Following on from establishing the prerequisites, it is possible to develop criteria that can be used to define applications for which design for composting may be of added value—these are shown in Table 1.

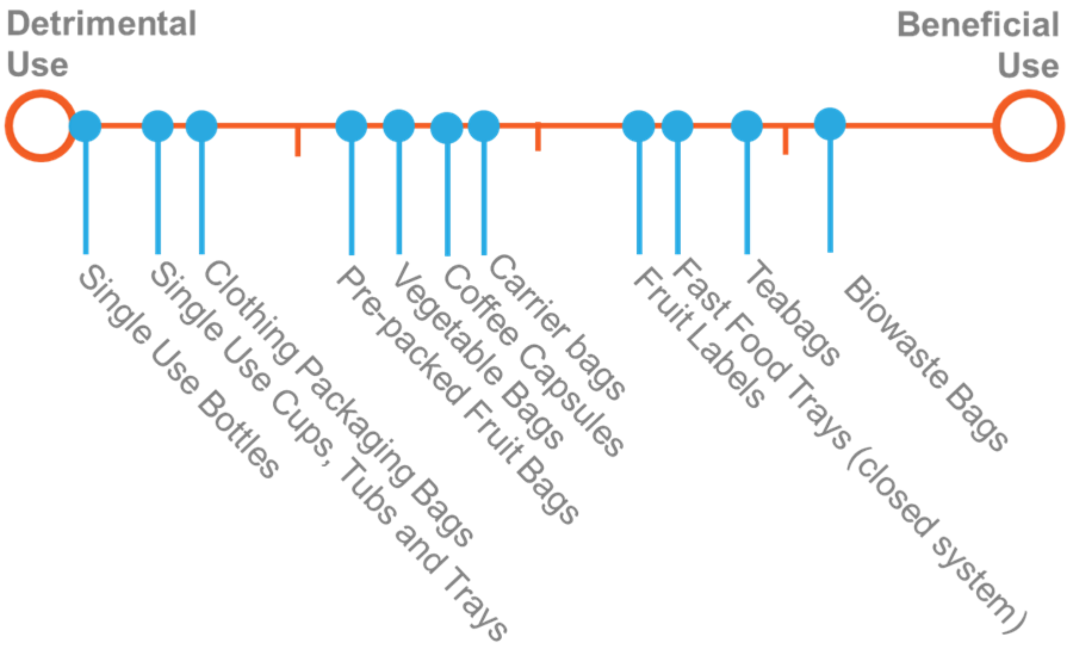
Table 1: Proposed Criteria for Identifying Applications for Which Design for Composting May Be of Added Value

	Criteria
1	**The use of compostable plastic brings 'environmental benefits' over alternative materials**
1a	This application could not have been designed for reuse or recycling or would not undergo material recycling even if designed for recycling
1b	The use of compostable plastic for this specific application can be expected to significantly increase the capture of bio-waste compared to non-compostable alternatives

1c	Through the use of LCA or similar environmental assessment tool, it can be demonstrated that compostable plastic is the preferred material for this particular application
2	**The use of compostable plastic does not directly or indirectly result in a reduction of the quality of the resulting compost**
2a	The use of compostable plastic for this application does not lead to consumer confusion and subsequent increase in contamination from non-compostable plastics.
2b	The use of compostable plastic for this application can be expected to significantly reduce the contamination of compost with non-compostable plastics (from this application) compared with current practice.

As seen in Figure 1, the study concludes that some of the most potentially beneficial applications are biowaste bags, teabags and fruit labels whereas applications such as single use bottles or clothing packaging bags constitute detrimental uses.

Figure 1: Compostable Plastics Beneficial Use Continuum



Compostable Plastics in Home Composting

This study assessed the evidence base for how plastic marketed as home compostable behave in home composting situations. It identifies the conditions that are found in different types of home composting systems used across the EU and compares them with the criteria set in existing standards. Based on this analysis, a set of recommendations have been formulated for approaches to address the discrepancies between existing frameworks and conditions to be found in practice.

Evidence for the Behaviour of Plastics Under Home Composting Conditions

Best practice in compost management includes:

- Selecting a container suitable for the climate, i.e. that helps to manage temperature and air access

- Ensuring that the balance of 'greens' (nitrogen) and 'browns' (carbon) is correct – the right (C:N) ratio
- Ensuring moisture levels are correct (around 50%) using a squeeze test and adjusted
- Ensuring sufficient aeration and mix of C/N materials through regular turning of the pile

The practices of six Member States (Belgium, France, Finland, Portugal, Spain and the UK) were analysed, informed from interviews and an analysis of publicly available information. These were selected to present a range of maturity in biowaste management along with a range of climatic conditions.

The following observations were made:

- National level composting advice is not always clear in terms of the method it is describing.
- Half the countries considered recommend including meat and fish waste in home composting, the other half strongly suggest not to.
- There are wide and varying sources of advice in each country and there is little reason to believe that the advice of the national organisations necessarily represents actual practice in the country concerned.
- Overall, the national differences in composting advice do not seem to be significant enough to lead to poor practices in some countries. If followed, the advice given should lead to a well-managed pile in all cases.

Only one of the sources of advice (from France) gave guidance to consumers on what to expect from composting plastics labelled as 'compostable', by indicating that there is likely to be a difference in 'theoretical performance' of the materials with actual performance.

There is a lack of robust studies that test how plastics marketed as home-compostable behave under home composting conditions. This report identified six studies that attempted to measure biodegradation of plastics marketed as home-compostable in home composting conditions. Of particular note is a study by ADEME in France took place in 2019 which found;

- incomplete biodegradation for both bags, with visible fragments in the compost after 18 months;
- no ecotoxicity concerns from the resulting compost, but neither were there any agronomic benefits from including the plastic material; and
- paper bag equivalents were shown to biodegrade in a much shorter timeframe with no visible residues.

Behavioural factors were also found to be a significant factor in the speed of the biodegradation process with the following found to speed up the process:

- Depositing the biowaste bag full of food waste, rather than empty;
- Regular mixing of the pile; and
- Starting the pile in springtime not winter.

Overall, this study and the others preceding it, show that **home composting of plastics marketed as home-compostable is a process which can present varied results and it is unclear how closely these meet consumer expectations.** The external influences, particularly behavioural ones, are likely to have a high influence on the final outcome.

Comparison Between Standards and Actual Home Composting Conditions

The main ways that home composting conditions differ to standard test conditions are:

1) **Duration –** The results of the ADEME study show that that fragments of plastic material can remain in the compost after 12 months, even when the rest of the organic material becomes compost.
2) **Temperature –** It is clear that the testing temperatures do not reflect actual real life conditions. Lower ambient temperatures (i.e. <20°C) will see slower biodegradation taking place. Its effects should be explored by changing the testing temperature to something that mirrors the conditions in a temperate climate, but still allowing for microbial activity to occur, i.e. not lower than 10°C.
3) **Inoculum-** The tests use a mature compost that is likely to be less biologically active than fresh waste that a householder will use—i.e. the test is harder to pass. However, the test inoculum is sieved, which increases surface area and may speed up the biodegradation process in comparison to a home environment.
4) **Form of the testing material –** materials tested in the form of smaller samples may perform differently when composted in their final product form.

There is also some disparity between standard testing regimes, real-life studies and the actual practice conducted by home composters. The latter has not been studied in any great detail and Standards assume that a 'well-managed' process is being undertaken. Given that individual practices have a large bearing on the effectiveness of composting, this is an assumption that will likely mean that at least some of the home compostable plastics will not perform in real-life as intended.

Recommendations for Plastics Home Composting Standards

As a way of strengthening the validity of the tests, some products that currently pass existing tests may need to be further tested under less optimal conditions to see how this affects the biodegradation and disintegration processes.

This report recommends that the draft CEN standard describes more clearly the add-as-you-go composting method whilst making explicit that this is likely to be a 'cold composting' process. This should include both a description of the range of abiotic conditions for which the test is deemed reliable (temperature, duration, pH, moisture), and related to this a set of practices which will ensure these conditions.

Inevitably, however the testing and labelling is refined, there will be a need for effective communication with the consumer. Labelling should give the consumer an expectation of a time frame for the composting of the plastic material and it should be made clear that novel indoor composting practices are not suitable. For a home composting labelling to function well it will need to be accompanied by a strong, possibly region specific, communications programme.

Home Composting of Plastics as Part of the Circular Economy

There appears to be no evidence to suggest that home compostable plastic material itself provides any specific benefits to the home compost and in the context of the circular economy, the material is essentially lost.

Because of this, the **applications are considerably narrowed compared with industrial composting, in order to avoid consumer confusion. In this case only biowaste bags, fruit labels and tea bags (heat sealed with plastic) are recommended.** The last two of these are likely to end up in home composting anyway, as attention has only recently been drawn towards the hidden plastic content of teabags.

Reusing carrier bags or vegetable bags as caddy liners for collecting biowaste for home composting may be a viable option, but there is still a danger of confusion leading to conventional (e.g. PE) bags being used; increased use of industrially compostable bags creates another layer of confusion. The recently declared approach in France mandates that all products marked as (industrially) compostable are also required to be home compostable, therefore the consumer does not need to make this distinction and confusion is potentially lessened.

Résumé – Français

En 2015, la Commission a adopté un plan d'action de l'UE pour l'économie circulaire afin de stimuler la transition de l'Europe vers une économie circulaire. Le nombre croissant de produits et d'emballages en plastique commercialisés comme étant «biodégradables» ou «compostables (à domicile)» soulève la question de savoir dans quelle mesure la biodégradabilité et la compostabilité (à domicile) du plastique sont bénéfiques dans le contexte de la transition vers une économie circulaire. Cette étude évalue les implications possibles de l'utilisation de ces produits et identifie les conditions / applications dans lesquelles la compostabilité industrielle ou domestique des produits ou des emballages pourrait apporter une valeur ajoutée par rapport à la réutilisation et et aux autres formes de valorisation.

Les résultats indiquent que les preuves sont faibles en faveur de tout avantage agronomique particulier associé à la matière plastique compostable dans le compost ou le digestat et que, par conséquent, les choix de matériaux pour les produits et les emballages devraient privilégier la recyclabilité par rapport à la compostabilité. Les exceptions à cette règle sont les cas où l'utilisation de plastique compostable a démontré des «avantages supplémentaires» tels que l'augmentation de la collecte des déchets organiques et leur détournement des déchets résiduels ou la réduction de la contamination du compost par le plastique. Les infrastructures de compostage industriel et de digestion anaérobie diffèrent considérablement dans l'UE et l'efficacité du traitement du plastique compostable varie même si les matériaux sont conformes à la norme harmonisée EN 13432 sur les exigences relatives aux emballages valorisables par compostage et biodégradation. Les résidus de plastique compostable non dégradés qui en résultent constituent un risque important qui ne peut être quantifié à l'heure actuelle.

Résumé Analytique - Français

Le marché des plastiques biodégradables

La capacité de production mondiale de tous les plastiques biodégradables en 2016 serait de 964.000 tonnes et on estime que 175.000 à 200.000 tonnes ont été produites pour le marché européen en 2016, environ la moitié de tous les produits plastiques biodégradables de l'UE étant vendus en Italie. Cela signifie que les plastiques biodégradables représentent environ 0,6% du marché total (35 millions de tonnes) des plastiques en Europe pour les produits visés par cette étude.

Les principales applications sont les sacs de transport et les sacs pour déchets biologiques, qui représentent ensemble près de 60% du marché des produits certifiés en nombre de certifications en 2019, et 68% de la masse des produits en plastique biodégradable trouvés sur le marché en 2015. Les autres emballages souples, les emballages rigides et les articles à usage unique tels que les plateaux, les tasses et les couverts représentent entre 2 et 12% du marché.

Le marché mondial des plastiques biodégradables est actuellement dominé par trois groupes différents de polymères : les polyesters, le PLA et les mélanges d'amidon. Ces polymères détiennent respectivement environ 27%, 24% et 42% du marché.

Nature et qualité du compost résultant des plastiques compostables

Les preuves directes d'une amélioration écologique grâce aux plastiques compostables sont rares et peu concluantes. Il semble y avoir un consensus sur l’absence du bénéfice nutritionnel et cela conduit donc à étudier plus en profondeur les avantages physiques potentiels de l'incorporation directe du carbone dans le sol sous forme de biomasse. Cependant, les preuves de l'ampleur de l'assimilation du carbone dans le compost sont également limitées. Ce n'est que récemment que le carbone du polymère a été suivi dans la biomasse, mais cela est difficile à quantifier à ce stade. Les recherches existantes suggèrent qu’au moins la moitié du plastique compostable est «perdue» en émissions atmosphériques de CO_2 lors de sa biodégradation dans le compostage. Le reste de la matière est incorporé à la biomasse dans le compost. Étant donné le peu de preuves disponibles, des recherches supplémentaires sont nécessaires.

Cette étude explore les types d'infrastructures de gestion des déchets organiques qui existent en Europe et les implications du traitement des plastiques compostables dans ces systèmes. **La digestion anaérobie** (**DA)** est de plus en plus considérée comme la méthode privilégiée pour traiter les déchets alimentaires d'un point de vue environnemental. L'acceptabilité des plastiques compostables sur les sites DA varie en fonction du schéma opérationnel du site qui varie, même au sein des pays. En ce qui concerne la biodégradation incomplète, plusieurs parties prenantes signalent qu’elle se produit dans les usines de DA et de compostage, le problème étant plus prononcé dans les usines de DA. Les mêmes problèmes ont été mis en évidence dans plusieurs pays.

Le compostage en cuve est un processus de compostage contrôlé exposé à l'oxygène plutôt qu'un processus de digestion en l'absence d'oxygène. Certains sites disposent de tamis primaires qui peuvent envoyer les plastiques et les plastiques compostables dans les rejets. C’est une pratique courante en Allemagne où les sacs en plastique classiques - qui sont souvent utilisés par les ménages pour livrer les biodéchets - sont retirés. **L’Allemagne utilise également du «compost frais» qui est généralement appliqué directement sur les terres agricoles, mais qui peut être composté pendant seulement 6 à 8 semaines, ce qui n’est généralement pas suffisant pour que la biodégradation des plastiques compostables se fasse complètement.** À l'inverse, l'Italie a une exigence minimale générale selon laquelle le compost doit être mûri pendant au moins 90 jours, ce qui est conforme aux hypothèses sur lesquelles semblent reposer les exigences de la norme EN 13432 (pour le traitement en conditions aérobies.

Il est important de noter **qu'aucune des règlementations des États Membres ou de l'UE sur la qualité du compost ou du digestat (résultant de l'un des processus ci-dessus) ne prend en compte les impacts des microplastiques sur l'environnement terrestre ou ne cherche à les réduire.** Actuellement, les contaminants plastiques d'une taille inférieure à 2 mm sont autorisés, ce qui dépasse la définition des microplastiques (généralement <1 mm). Cette situation est potentiellement problématique pour tous les types de plastique, mais dans le contexte du présent rapport, une biodégradation ou une fragmentation incomplète peut créer des particules de plastique qui tombent en dessous de ces valeurs limites et ne sont donc pas ciblées pour être éliminées.

Effets de la contamination des plastiques collectés séparément pour le recyclage des matériaux

En ce qui concerne les plastiques compostables dans le recyclage des plastiques mécaniques conventionnels, les rapports indiquent que les niveaux finaux de contamination sont acceptables pour les processus de recyclage ultérieurs. Toutefois, cela fait référence à un scénario dans lequel les plastiques compostables ne sont utilisés qu'en très petites quantités dans des applications de niche. Une utilisation plus répandue dans les emballages, en particulier si des emballages plus rigides sont utilisés, peut nécessiter une adaptation des lignes de tri, ou générer des niveaux de contamination susceptibles de poser des problèmes pour le recyclage mécanique. En Italie, où l'utilisation des plastiques compostables est déjà très répandue (avec une concentration par rapport aux plastiques conventionnels au moins cinq fois supérieure à celle de tout autre pays de l'UE), le taux de contamination global est inférieur aux niveaux considérés comme préoccupants pour le recyclage mécanique avant le tri.

Performance environnementale des produits alternatifs non plastiques biodégradables par rapport au plastique compostable

Les produits de substitution biodégradables non plastiques tels que le papier peuvent être utilisés pour remplir la même fonction que les plastiques compostables. Cependant, il existe peu de littérature comparant les produits en plastique compostables aux produits biodégradables non plastiques.

Trois études sur les sacs de transport montrent des résultats différents lorsqu'on compare des sacs de transport en papier et en plastique compostable. Deux des trois études constatent que le sac en plastique compostable a généralement une charge environnementale plus faible ou très similaire à celle d'un sac en papier, mais les hypothèses générales des études, y compris la manière dont la réutilisation est incorporée, ont une plus grande incidence sur le résultat global.

Une autre étude sur le film d'emballage n'a généralement pas été concluante, car certaines catégories d'impact environnemental ont montré que l'alternative non plastique a un impact environnemental plus faible et dans d'autres catégories d'impact, le plastique compostable est plus performant ; il est donc difficile de tirer des conclusions spécifiques et il **ne semble pas y avoir de preuve claire que les alternatives biodégradables non plastiques sont préférables aux plastiques compostables sur le plan environnemental.**

Les principaux points à retenir sont les suivants : par rapport à la production, **la phase de fin de vie contribue souvent peu aux impacts globaux,** mais **la mise en décharge des plastiques compostables devrait être évitée** afin de réduire les impacts du changement climatique dus au dégagement de méthane. En ce qui concerne la production, **les matières premières et l'utilisation d'énergie ont la plus grande influence et les produits biologiques compostables peuvent offrir des avantages dans certaines catégories d'impact**, en particulier le changement climatique, mais présentent des impacts plus élevés dans d'autres catégories que les plastiques à base de fossiles si l'on considère un traitement de fin de vie moyen dans l'UE.

Le risque de jeter des déchets de plastiques biodégradables

Il n'y a pas de preuves empiriques récentes et concluantes qui établissent clairement une corrélation entre la commercialisation d'emballages ou de produits en plastique comme étant biodégradables/compostables et une augmentation de la tendance à les jeter dans la nature - des recherches supplémentaires sont nécessaires. Toutefois, plusieurs études indiquent **que les consommateurs ont l'impression que les termes «biodégradable» ou «compostable» sont un aspect intrinsèquement vertueux** d'un produit et que le fait de jeter un tel article aurait moins d'impact. Certains éléments indiquent également **que la perception du temps nécessaire à la biodégradation de ces plastiques n'est probablement pas conforme à la réalité.**

Révision des normes de compostabilité industrielle - EN 13432

Il existe actuellement deux normes harmonisées pour la biodégradation dans le compostage industriel et la digestion anaérobie : la norme EN 13432 est en place depuis 2000 et est liée à la directive européenne sur les emballages et les déchets d'emballages (94/62/CE), où le respect de la norme présuppose la conformité aux exigences essentielles de la directive. La norme EN 14995 contient des critères identiques, mais son champ d'application s'étend à d'autres produits en plastique sans emballage. Les recherches menées pour ce rapport ont permis d'identifier deux critiques principales des normes:

- **Les durées des tests de biodégradation et de désintégration aérobie sont trop longues.**
- **Les hypothèses du test de biodégradation anaérobie ne reflètent pas la réalité.**

Il est recommandé que la norme EN 13432 (et par conséquent EN 14995) soit mise à jour pour refléter les dernières connaissances et approches scientifiques. Cela comprend l'obligation de **tester séparément et de satisfaire aux critères de biodégradation de tous les constituants organiques** présents dans la matière à une concentration comprise entre 1% et 15% et **d'introduire un test d'inhibition de la nitrification et un test de toxicité pour les vers de terre.** Il **pourrait être utile d'introduire un test pour valider la performance de biodégradation dans le sol.**

Il existe également plusieurs autres faiblesses potentielles, en particulier en ce qui concerne le seuil de temps de test et son lien avec la réalité. Il **est recommandé aux États membres de mener leurs propres essais pour déterminer si la norme est** adaptée à la vérification de la performance des plastiques compostables (en notant que le terme performance est un terme relatif qui sera dicté par les exigences locales en matière de processus et de qualité du compost). Cela aidera à déterminer s'ils doivent accepter ou non les plastiques compostables dans leurs installations de traitement des biodéchets.

Critères pour lesquels l'utilisation de produits et d'emballages compostables pourrait être bénéfique

Sur la base des résultats précédents, les points suivants résument la base de la fixation des critères:

- À ce stade, les preuves sont faibles en faveur de tout avantage agronomique particulier associé à la matière plastique compostable dans le compost ou le digestat. Une partie du carbone des plastiques biodégradables semble être incorporée dans la biomasse, mais au moins la moitié est «perdue» en raison des émissions atmosphériques de CO_2. Cela conduit à la conclusion que les choix de matériaux pour les produits et les emballages devraient privilégier la recyclabilité par rapport à la compostabilité.
- Les exceptions à cette règle sont les cas où l'utilisation de plastique compostable a démontré des «avantages supplémentaires» tels que l'augmentation de la collecte des déchets organiques et leur détournement des déchets résiduels ou la réduction de la contamination plastique du compost, facilitant ainsi la circularité dans la bioéconomie.
- Les infrastructures industrielles de compostage et de digestion anaérobie ainsi que les pratiques de collecte des déchets organiques diffèrent considérablement dans l'UE et ne sont pas toutes efficaces pour traiter le plastique compostable.
- La conformité des matériaux à la norme EN 14432 ne conduit pas automatiquement à un traitement efficace des plastiques compostables et la norme peut nécessiter une modification pour en accroître la pertinence et l'efficacité.
- Les résidus de plastique compostable non dégradés dans le compost ou le digestat constituent un risque important qui ne peut être quantifié à l'heure actuelle. Ce risque n'est pas atténué par les protocoles sur la qualité des engrais au niveau des États membres ou de l'UE (règlement sur les engrais), qui n'exigent pas actuellement l'absence de microplastiques (<2 mm).

Il convient de définir les conditions préalables à remplir pour que l'élimination des emballages compostables en même temps que les biodéchets soit considérée comme une option. Il s'agit de s'assurer que;

- L’infrastructure de traitement des déchets organiques est capable de traiter ces matériaux / produits sans effets négatifs;
- Le matériau / produit fonctionne comme prévu dans le compostage industriel; et,
- La méthode de traitement des déchets et les mesures d'élimination appropriées requises par l'utilisateur final pour faciliter cette opération sont communiquées efficacement.

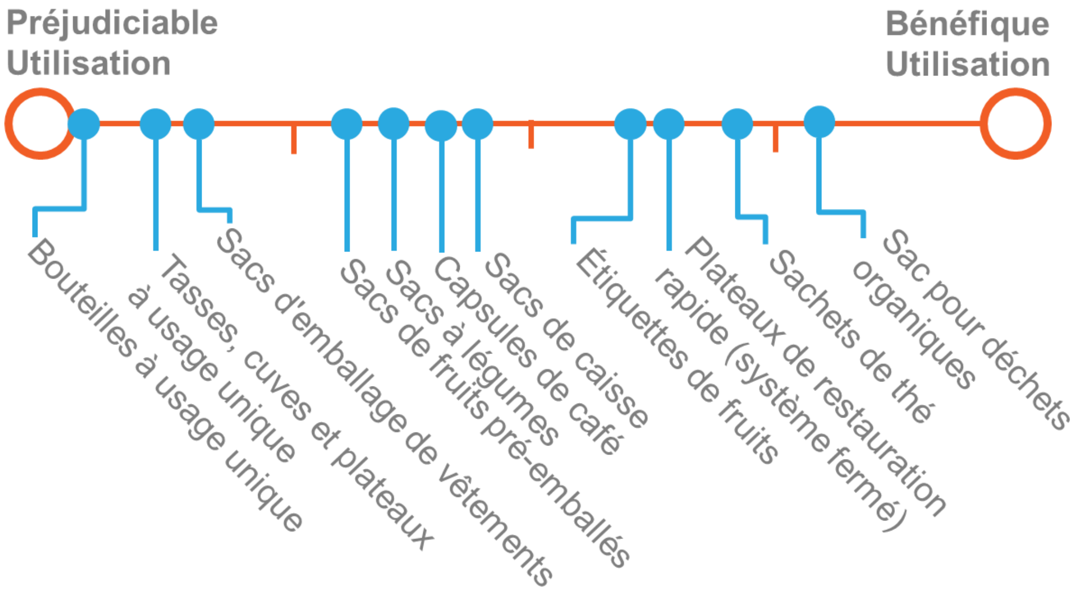
Sans ces trois éléments ci-dessus, la probabilité de conséquences négatives est élevée, c'est-à-dire que la confusion des consommateurs entraîne une élimination incorrecte et / ou des situations où le traitement des déchets organiques est entravé. Après avoir établi les conditions préalables, il est possible de développer des critères qui peuvent être utilisés pour définir les applications pour lesquelles la conception pour le compostage peut apporter une valeur ajoutée – ceux-ci sont présentés dans le Tableau 1.

Tableau 1: Critères proposés pour identifier les applications pour lesquelles la conception pour le compostage peut être une valeur ajoutée

	Critères
1	**L'utilisation de plastique compostable apporte des «avantages environnementaux» par rapport aux matériaux alternatifs**
1a	Cette application ne peut pas avoir été conçue pour la réutilisation ou le recyclage ou ne serait pas soumise au recyclage des matériaux même si elle était conçue pour le recyclage.
1b	L'utilisation de plastique compostable pour cette application spécifique devrait permettre d'augmenter considérablement le captage des biodéchets par rapport aux solutions de remplacement non compostables
1c	Grâce à l'utilisation de l'ACV ou d'un outil d'évaluation environnementale similaire, il peut être démontré que le plastique compostable est le matériau préféré pour cette application particulière
2	**L'utilisation de plastique compostable n'entraîne pas, directement ou indirectement, une réduction de la qualité du compost obtenu**
2a	L'utilisation de plastique compostable pour cette application n’entraine pas de confusion pour le consommateur et n’augmente pas la contamination par des plastiques non compostables.
2b	L'utilisation de plastique compostable pour cette application devrait permettre de réduire considérablement la contamination du compost par des plastiques non compostables (à partir de cette application) par rapport à la pratique actuelle.

Comme le montre la Figure 1, l'étude conclut que certaines des applications les plus bénéfiques sont les sacs de biodéchets, les sachets de thé et les étiquettes de fruits, tandis que les applications telles que les bouteilles à usage unique ou les sacs d'emballage de vêtements constituent des utilisations préjudiciables.

Figure 1 : Continuum des utilisations bénéfiques des plastiques compostables



Plastiques compostables dans le compostage domestique

Cette étude a évalué la base de données sur la façon dont le plastique commercialisé comme compostable à domicile se comporte dans les situations de compostage domestique. Elle identifie les conditions rencontrées dans les différents types de systèmes de compostage domestique utilisés dans l'UE et les compare aux critères définis dans les normes existantes. Sur la base de cette analyse, un ensemble de recommandations a été formulé concernant les approches à adopter pour remédier aux écarts entre les cadres existants et les conditions que l'on trouve dans la pratique.

Données probantes sur le comportement des plastiques dans les conditions de compostage domestique

Les meilleures pratiques de gestion du compost comprennent:

- La sélection d'un conteneur adapté au climat, c'est-à-dire qui aide à gérer la température et l'accès à l'air
- Veiller à ce que l'équilibre entre les «verts» (azote) et les «bruns» (carbone) soit correct - le bon rapport (C: N)
- S'assurer que les niveaux d'humidité sont corrects (environ 50%) en utilisant un test de compression et ajusté
- Assurer une aération suffisante et un mélange des matériaux C/N par un retournement régulier de la pile

Les pratiques de six États membres (Belgique, France, Finlande, Portugal, Espagne et Royaume-Uni) ont été analysées, fondées sur des entretiens et une analyse des informations accessibles au public. Ils ont été sélectionnés pour présenter une gamme de maturité dans la gestion des biodéchets ainsi qu'une gamme de conditions climatiques.

Les observations suivantes ont été faites:

- Les conseils de compostage au niveau national ne sont pas toujours clairs en termes de méthode qu'ils décrivent.

- La moitié des pays considérés recommandent d'inclure les déchets de viande et de poisson dans le compostage domestique, l'autre moitié suggère fortement de ne pas le faire.
- Les sources de conseils sont nombreuses et variées dans chaque pays et il y a peu de raisons de croire que les conseils des organisations nationales représentent nécessairement la pratique réelle dans le pays concerné. Dans l'ensemble, les différences nationales en matière de conseils sur le compostage ne semblent pas suffisamment importantes pour conduire à de mauvaises pratiques dans certains pays. S'ils sont suivis, les conseils donnés devraient dans tous les cas conduire à une pile bien gérée.

Seule une des sources de conseil (en France) a donné des conseils aux consommateurs sur ce qu'ils peuvent attendre du compostage de plastiques étiquetés comme «compostables», en indiquant qu'il y a probablement une différence entre la «performance théorique» des matériaux et leurs performances réelles.

Il y a un manque d'études robustes qui testent comment les plastiques commercialisés comme compostables à domicile se comportent dans des conditions de compostage domestique. Ce rapport a identifié six études qui ont tenté de mesurer la biodégradation des plastiques commercialisés comme compostables à domicile dans des conditions de compostage domestique. Il convient de noter en particulier une étude réalisée par l'ADEME en France en 2019, qui a constaté;

- Une biodégradation incomplète pour les deux sacs, avec des fragments visibles dans le compost après 18 mois;
- Qu'il n'y a pas de problème d'écotoxicité du compost résultant, mais il n'y a pas non plus d'avantages agronomiques à inclure la matière plastique; et
- Il a été démontré que les équivalents de sacs en papier se biodégradent dans un délai beaucoup plus court, sans résidus visibles.

Les facteurs comportementaux se sont également révélés être un facteur important dans la rapidité du processus de biodégradation, les éléments suivants ayant accéléré le processus:

- Déposer le sac de biodéchets rempli de déchets alimentaires, plutôt que vide;
- Mélange régulier de la pile; et
- Démarrage de la pile au printemps et non en hiver.

Dans l'ensemble, cette étude et les précédentes montrent que **le compostage domestique des plastiques commercialisés comme compostables à domicile est un processus qui peut présenter des résultats variés et il n'est pas clair dans quelle mesure ceux-ci répondent aux attentes des consommateurs.** Les influences externes, notamment comportementales, sont susceptibles d'avoir une forte influence sur le résultat final.

Comparaison entre les normes et les conditions réelles de compostage à domicile

Les principales différences entre les conditions de compostage domestique et les conditions d'essai standard sont les suivantes:

1) Durée - Les résultats de l'étude ADEME montrent que des fragments de matière plastique peuvent rester dans le compost après 12 mois, même lorsque le reste de la matière organique devient du compost.
2) Température - Il est clair que les températures d'essai ne reflètent pas les conditions réelles de la vie quotidienne. Des températures ambiantes plus basses (c.-à-d. <20 oC) entraîneront une biodégradation plus lente. Il convient d'étudier ses effets

en modifiant la température de test de manière à ce qu'elle reflète les conditions d'un climat tempéré, tout en permettant à l'activité microbienne de se produire, c'est-à-dire en ne descendant pas en dessous de 10oC.

3) Inoculum - Les tests utilisent un compost mature qui est probablement moins actif biologiquement que les déchets frais qu'un ménage utilisera — c'est-à-dire que le test est plus difficile à réussir. Cependant, l'inoculum de test est tamisé, ce qui augmente la surface et peut accélérer le processus de biodégradation par rapport à un environnement domestique.
4) Forme du matériel d'essai - les matériaux testés sous forme d'échantillons plus petits peuvent se comporter différemment lorsqu'ils sont compostés dans leur forme de produit final.

Il existe également une certaine disparité entre les régimes de test standard, les études en situation réelle et la pratique réelle des composteurs à domicile. Cette dernière n'a pas été étudié en détail et les normes supposent qu'un processus «bien géré» est en cours. Étant donné que les pratiques individuelles ont une grande influence sur l'efficacité du compostage, cette hypothèse signifie qu'au moins une partie des plastiques compostables a domicile ne se comporteront pas comme prévu dans la vie réelle.

Recommandations pour les normes de compostage domestique des plastiques

Afin de renforcer la validité des tests, certains produits qui réussissent actuellement les tests existants pourraient devoir être testés davantage dans des conditions moins optimales pour voir comment cela affecte les processus de biodégradation et de désintégration.

Ce rapport recommande que le projet de norme CEN décrive plus clairement la méthode de compostage à la demande tout en précisant qu'il s'agit probablement d'un processus de «compostage à froid». Cela devrait inclure à la fois une description de la gamme des conditions abiotiques pour lesquelles le test est jugé fiable (température, durée, pH, humidité) et, en relation avec cela un ensemble de pratiques qui garantiront ces conditions.

Inévitablement, quelle que soit la précision des tests et de l'étiquetage, il sera nécessaire de communiquer efficacement avec le consommateur. L'étiquetage devrait donner au consommateur un délai pour le compostage de la matière plastique et il devrait être clairement indiqué que les nouvelles pratiques de compostage en intérieur ne sont pas adaptés. Pour qu'un étiquetage de compostage domestique fonctionne bien, il devra être accompagné d'un programme de communication solide, éventuellement spécifique à la région.

Le compostage domestique des matières plastiques dans le cadre de l'économie circulaire

Rien ne semble indiquer que la matière plastique compostable à domicile apporte en soi des avantages spécifiques au compost domestique et, dans le contexte de l'économie circulaire, la matière est essentiellement perdue.

De ce fait, **les applications sont considérablement réduites par rapport au compostage industriel, afin d'éviter toute confusion chez le consommateur. Dans ce cas, seuls les sacs de biodéchets, les étiquettes de fruits et les sachets de thé (thermoscellés avec du plastique) sont recommandés**. Les deux derniers sont de toute façon susceptibles de se retrouver dans le compostage domestique, car l'attention n'a été attirée que récemment sur le contenu plastique caché des sachets de thé.

La réutilisation des sacs de transport ou des sacs de légumes comme sacs de caddie pour la collecte des biodéchets en vue du compostage domestique peut être une option viable, mais il existe toujours un risque de confusion conduisant à l'utilisation de sacs conventionnels (par exemple PE); l'utilisation accrue de sacs compostables industriellement crée une autre couche de confusion. L'approche récemment déclarée en France exige que tous les produits marqués comme étant compostables (industriellement) soient également compostables à domicile, le consommateur n'a donc pas besoin de faire cette distinction et la confusion est potentiellement atténuée.

Contents

Glossary

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

Anaerobic Digestion	The breakdown of organic material by micro-organisms in the absence of oxygen which produces biogas, which can be burned for energy onsite or upgraded for injection into the gas network, and digestate, which can be used as a fertiliser.
Conventional Plastic	Plastic derived from fossil-based feedstocks that is not considered to be biodegradable or compostable in any reasonable timeframe
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 (Biodegradation)	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.
Compostable Plastic	Plastic that biodegrades in industrial composting and is compliant with EN 13432 or equivalent national standard.
EN 13432	The European standard "Requirements for packaging recoverable through composting and biodegradation." This is the standard used to test that a plastic material is compostable in industrial composting, but it applies to packaging irrespectively of the material they are made of.
Industrial Composting	A blanket term which includes all forms of centralised organic waste treatment that is characterised by high levels of control and results in various forms of soil improver.
Home Compostable Plastic	Plastic that biodegrades in home compost within a reasonable timeframe.
Certifications	Third party testing to an established test method or standard. Often including a labelling scheme. Also includes certifications that do not have international standards associated with them such as the marine and fresh water environments.
Energy from Waste (EfW)	Incineration of residual waste where energy is recovered as electricity and/or heat
Materials recycling Facility (MRF)	A plant that receives, separates and prepares recyclable materials for sale to material manufacturers
NPK	Macro-nutrients in fertilisers: nitrogen (N), phosphorus (P) and potassium (K) or NPK.

Material Abbreviations

The following is a list of the material acronyms and abbreviations that are used in this report

PLA	Polylactic acid
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PET	Polyethylene Terephthalate
Bio-PET	Bio-based Polyethylene Terephthalate
(HD) (LD) PE	(High density) (Low Density) Polyethylene
Bio-PE	Bio-based Polyethylene
PEF	Polyethylenefuranoate
PP	Polypropylene
Bio-PP	Bio-based polypropylene
PA	Polyamides
Bio-PA	Bio-based Polyamides
PCL	Polycaprolactone
PVA	Polyvinyl Alcohol
MEG	Monoethylene Glycol
LA (D-LA and (L-LA)	Lactic Acid

1.0 Introduction

In 2015 the Commission committed itself to promoting a circular economy with its EU action plan for the circular economy setting out the actions that will be taken to drive "the transition to a more circular economy[1], where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised". More recently, in January 2018, the Commission adopted a Strategy for Plastics in a Circular Economy[2] which laid the foundation for a new plastics economy where the design and production of plastics and plastic products fully respect reuse, repair and recycling needs, and more sustainable materials are developed and promoted. The Plastics Strategy, inter alia, sets out that, "by 2030, all plastic packaging placed on the market should be reusable or recyclable in a cost-effective manner". As regards the increasing market shares of plastics with biodegradable properties, the Strategy takes a cautious approach and states that it brings new opportunities as well as risks and adds that "in the absence of clear labelling or marking for consumers, and without adequate waste collection and treatment, it could aggravate plastics leakage and create problems for mechanical recycling".

The growing number of plastic products and packaging being marketed as 'biodegradable' or '(home) compostable' however raises the question of the extent to which biodegradability and (home) compostability of plastic is a beneficial feature in the context of the broader circular economy agenda. The Plastic Strategy recognised this, pointing to the need to identify the applications where biodegradable plastics have clear environmental benefits and clarifying how they should be handled after use. It also identifies specific challenges stressing that "most currently available plastics labelled as biodegradable generally degrade under specific conditions which may not always be easy to find in the natural environment, and can thus still cause harm to ecosystems". A number of questions as to the broader implications are as yet unanswered, including the implications of the increase in biodegradable plastics on the reuse and recycling of non-biodegradable plastic products and packaging, the feasibility of generally applicable criteria or standards for biodegradation in home-composting in an EU context, effects on the quality of the compost, the form of their potential contribution to litter prevention4, and related consumer information and incentives.

Identifying "the conditions where the use of compostable and biodegradable plastics is beneficial" requires, inter alia, to clarify the conditions under which using biodegradable and (home) compostable plastics for products and packaging can be of added value when compared to reuse or other end-of life treatment options.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52015DC0614

[2] https://ec.europa.eu/environment/waste/plastic_waste.htm

Regarding challenges relating to consumer information the Plastic Strategy points out that *"plastics labelled 'compostable' are not necessarily suitable for home composting"* and that "*it is important to ensure that consumers are provided with clear and correct information, and to make sure that biodegradable plastics are not put forward as a solution to littering"*. The Strategy announces that the Commission will *"start work to develop harmonised rules on defining and labelling compostable and biodegradable plastics"*. The Staff Working Document accompanying the Strategy5 stresses that *"it is of utmost importance that consumers are properly informed and aware of the meaning of the different concepts and of the proper handling or end-of-life treatment, the risk being that plastic items are incorrectly handled or disposed of at the end of their useful life"*.

In light of the above the European Commission, DG Environment, has commissioned a study in the context of its ongoing work related to a framework for plastics with biodegradable properties. The overall objectives of this study were to:

- provide an overview of the market and regulatory situation with regard to biodegradable/ compostable plastic products and packaging;
- assess possible implications of the use of such products in a circular economy context, in particular on waste management and in light of conditions found in practice in home composting systems across the EU (in terms of leakage of compostable plastics into the open environment and for the quality of the compost); and,
- identify conditions/ applications in which biodegradability/ (home) compostability of products or packaging could be of added value when compared to reuse and other forms of recovery and clarify the basis for establishing such conditions/ applications. Identification of relevant benchmarks in relation to the "added value".
- provide an overview of biodegradability criteria set in existing home-compostability frameworks (standards, legislation, certification schemes)
- assess the practical relevance and limitations of such criteria in light of conditions found in practice in home-composting systems across the EU and identify possible measures for addressing discrepancies.
- develop related recommendations.

The report is laid out in the following sections:

- **Section 2.0 Key** Definitions
  This section discusses some of the key definitions that need to be understood as a prerequisite for reading the rest of the report. This includes terms such as 'compostable' and 'biodegradable', what these mean in practice and in European law.

- **Section 3.0 The EU Biodegradable Plastics Market**
  The section look sat the EU market for biodegradable and compostable plastics; what the key materials are, the key applications, the extent of certification of

such products, consumer information provided, and provides and outlook for the future market.

- Section 4.0 **Impacts of an Increase in the Market for Compostable Consumer Plastic Products and Packaging**
  This section looks at developing a better understanding of the role of biodegradability in the context of circular economy and possible trade-offs associated with making products or packaging biodegradable/compostable rather than reusable or recyclable.

  In order to achieve this, the following aspects are discussed in subsequent sections:

  - Establishing the nature and quality of compost resulting from the composting of biodegradable/compostable plastics
  - Implications of Compostable Plastics in Organic Waste Processing
  - Establishing the effect of biodegradable/compostable plastics entering plastics recycling streams
  - Analysing the evidence base for the littering risks associated with biodegradable/compostable plastics

- Section 5.0 **Review of EN 13432**
  This section addresses the key criticisms that have been aimed at EN 13432 and evaluates how these may be included in any future update and sets out recommendations for this.

- Section 6.0 **Environmental Performance of Compostable Plastics**
  An overview of some of the issues around determining and comparing environmental performance of compostable plastics compared with alternatives.

- Section 7.0 **Criteria Setting**
  This section of the report brings together the knowledge of previous sections to assess the possible conditions in which the use of compostable products and packaging is beneficial. Criteria are derived that specific applications can be tested to.

- Section 8.0 **Compostable Plastics in Home Composting**
  This section of the report looks at the systems and practices of home composting in example Member States. It then looks at the conditions in home composting and the evidence base for what happens to compostable plastics in practice. This is then compared with the current Standards and recommendations are made.

An Appendix with supporting information is available as a separate document

2.0 Key Definitions

2.1 Biodegradable and Compostable

When discussing biodegradability, it is important to note that almost all materials ultimately biodegrade, even in the open environment. However, conventional, fossil-based plastic items are predicted to take many hundreds of years; this is not a meaningful timeframe in human terms and can cause many problems to ecosystems over this time. Larger conventional plastic items will also progressively break down into microplastics which are known to be ingested by both aquatic and terrestrial organisms[3] —the use of biodegradable plastics for some applications is often thought to reduce the risk of this.

The biodegradability of a plastic is also influenced heavily by the environmental conditions that it is in, for example one plastic may biodegrade relatively quickly in one environment but take hundreds of years in a different environment. The rate of decomposition is affected by the presence of bacteria, fungi and oxygen, hence why a 'biodegradable' material may decompose in industrial composting but not (or at a considerably slower rate) on land or in a marine environment. It is therefore necessary to define both the environment and the timeframe when talking about biodegradation.

There are many definitions for biodegradation, which generally do not specify a particular environment or timeframe. It should be emphasised that the term biodegradable, when referring to plastics, has little or no meaning *in a policy context* without a clear specification of the exact environmental conditions that this process is expected to occur in and the required maximum timeframe.

EN 13432 and EN14995 on the compostability of packaging and non-packaging plastics respectively 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".*

This definition is similar to ones provided by other standards organisations and helps to explain the process of biodegradation from a basic scientific perspective. Definitions can become more meaningful when talking about specific environments, for example industrial or home composting. The Directive on the reduction of the impact of certain

[3] Eunomia Research & Consulting (2018) *Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products*, Report for European Commission, February 2018

plastic products on the environment (commonly known and henceforth in this report referred to as the single use plastics (SUP) Directive) was enacted in July 2019;[4] It includes Article 3(16) which states that:

> *'biodegradable plastic' 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;*

This is the first time that the term biodegradable is linked explicitly with composting and anaerobic digestion (AD) in European law and the first time that biodegradable plastic has been defined. While the SUP provides for a definition it does not in its scope distinguish conventional from biodegradable plastics – both are covered by the Directive in the same way. The Directive requires an evaluation by 3 July 2027 of the technical progress concerning criteria or a standard for biodegradability in the marine environment.

The Packaging and Packaging Waste Directive (PPWD) refers to biodegradable and compostable packaging in its 'Essential Requirements' (which all packaging needs to comply with to be allowed on the EU market). The two relevant requirements are:[5]

Annex II (3c):

> *"**Packaging recoverable in the form of composting***
>
> *Packaging waste processed for the purpose of composting shall be of such a biodegradable nature that it **does not** [6]hinder the separate collection and the composting process or activity into which it is introduced."*

Annex II (3d):

> ***"Biodegradable packaging***
>
> *Biodegradable packaging waste shall be of such a nature that it is capable of undergoing physical, chemical, thermal or biological decomposition such that most of the finished compost ultimately decomposes into carbon dioxide, biomass and water. Oxo-degradable plastic packaging shall not be considered as biodegradable."*

For Member States one of the key issues is whether biodegradable plastic that are separately collected with organic waste and that enters aerobic or anaerobic treatment can be counted towards packaging recycling rates and in some cases may have implication in the achievement of the plastics packaging recycling targets of 50% by 2025 and 55% by 2030. To that end, Article 6a (4) of the Packaging and Packaging Waste Directive 94/62/EC states that;

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

[5] European Parliament and the Council (2018) Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste

[6] Until a 2018 amendment these words were 'should not'

*"For the purposes of calculating whether the [recycling] targets… have been attained, the amount of **biodegradable packaging waste** that enters aerobic or anaerobic treatment **may be counted as recycled** where that treatment generates compost, digestate, or other output with a **similar quantity** of recycled content in relation to input, which is to be used as a recycled product, material or substance. **Where the output is used on land**, Member States may count it as recycled only if this use results in **benefits to agriculture or ecological improvement**."*

The final phrase "benefits to agriculture or ecological improvement" is key and is discussed further in Section 4.1.

The current situation in EU law therefore leads us to two conclusions:

1) Industrial composting or AD are the only acceptable waste disposal methods for biodegradable plastics that may potentially contribute to the recycling rate of a Member State.
2) EN 13432 is the de facto method for verifying that compostable plastics meet the essential requirements for packaging recoverable in the form of composting.

Therefore, for the purposes of this study the definition of **compostable plastics** is the following:

Any packaging product that is certified to conform to EN 13432 – Requirements for packaging recoverable through composting and biodegradation – or any equivalent national standard.

Any non-packaging product that is certified to conform to EN 14995 - Plastics - Evaluation of compostability - Test scheme and specifications – or any equivalent national standard.

Industrial composting attempts to create exactly the right balance of all the important factors to make the process as fast as possible. The types and concentration of micro-organisms that metabolise the materials are highly controlled. All other environments such as in soil, fresh or marine water, are not controlled in any way and therefore the time for a material to biodegrade will vary massively.

There is a general hierarchy of 'aggressiveness' for environments, with industrial composting being the most aggressive and the oceans being one of the least aggressive – see Figure 2.

Figure 2: Hierarchy of aggressiveness for biodegradation environments

More Aggressive Environment (↑)

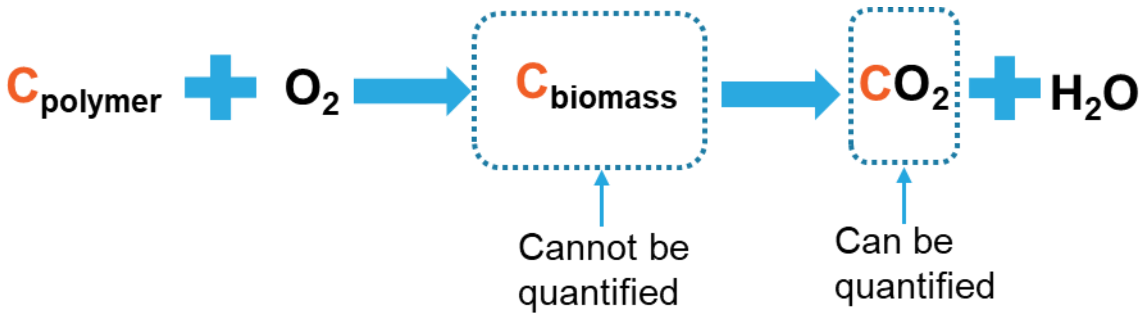
Environment	Conditions
Industrial Composting	High temperature (>58°C) Fungi and bacteria
Anaerobic Digestion Plant*	Elevated temperature (20-45°C) Bacteria
Home Composting	Ambient temperature (20-30°C)** Fungi and bacteria
Soil	Ambient temperature Fungi and bacteria
Fresh Water	Ambient temperature Bacteria only
Marine Water	Ambient temperature (<5 - >20°) Diluted bacteria
Landfill***	Ambient temperature Bacteria only

*included are mesophilic digestors, which make up 90% of ADs.
**figures here are for normal garden composting, composting cages can reach 60°C
***landfill may be more or less aggressive throughout its life and depending upon how it is managed. As it transitions from aerobic to anaerobic, material that needs aerobic conditions may not biodegrade.

Source: Adapted from- Degradable Polymers and Materials – Principles & Practice,33-43, 2012. Editors: Khemani, K. and Scholz, C

2.2 The Biodegradation Process

As biodegradation is the degradation caused by biological activity the material must therefore be capable of being assimilated by microorganisms (primarily bacteria and fungi). The aerobic process shown in the simplified equation below 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.



Source: Adapted from Chinaglia et al[7]

The way to gauge the progress of this process is to measure the consumption of oxygen or the production of CO_2. Biodegradation percentage is most often calculated as the ratio between the CO_2 produced and the theoretical CO_2 if all of the carbon in the material were oxidised. A proportion of the carbon will always be converted to biomass and therefore 100% biodegradation will not result in 100% mineralisation (i.e. 100% of the available carbon converted to CO^2).[8] There is yet to be a 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.[9]

2.3 Home Compostable

A material may be termed 'home compostable' if it can biodegrade in a home composting environment. The practice and attitude of home composters, however, vary widely from household to household, and with different temperatures and microorganisms depending on both material input and geography. These highly variable conditions mean that it can be hard to define if a material is 'home-compostable', and at the time of writing no European standard for defining home compostability exists. However there are independent certifications and some Member States including France and Belgium have their own local standards/decrees—this and all further discussion on home composting can be found in more detail in Section 5.0.

2.4 Bio-based and Fossil-based Compostable Plastics

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

[7] 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

[8] 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

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

in a composting (or any other) 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 more precise term of bio-based helps to remove some of the ambiguity.

It is possible and becoming increasingly common for conventional plastics such as polyethylene (PE) and polyethylene terephthalate (PET) 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.

Equally, for a plastic material to be compostable it is not required to be made from bio-based materials. There are several compostable plastics that can be made from fossil-based material. It is therefore important not to confuse what the material is made from with its possible end of life options. That being said, a large proportion of compostable plastics used in packaging are from a bio-based source and the trend is to move increasingly towards this. There are several definitions for the term 'bio-based plastic' however most are similar to the one used by the International Union of Pure and Applied Chemistry[10]:

> *"a polymer composted or derived in whole or in part of biological products issued from biomass (including plant, animal, and marine or forestry materials)."*

It is important to note that under most definitions, a product can be referred to as bio-based even if it has mostly fossil-based content – see Figure 3 for one such example, although there's no agreed definition for this at present. As such, when looking at the feedstock for each polymer type it is important to look at bio-based content. The bio-based content is the amount of biomass used by percentage of weight to create the final product. It is measured in accordance with EN 16640 or EN 16785. No environmental benefits are claimed by these types of labels or certifications although the perception of consumers may be that there is an implied 'greenness'. The provenance of the feedstock is usually not a criterion that is assessed and therefore a higher bio-based content is no guarantee of improved environmental credentials (and vice-versa).

Figure 3: TUV Austria Certification for Bio-based Plastics

OK biobased TÜV AUSTRIA ★	OK biobased TÜV AUSTRIA ★★	OK biobased TÜV AUSTRIA ★★★	OK biobased TÜV AUSTRIA ★★★★
20-40% Bio-based	**40-50% bio-based**	**60-80% Bio-based**	**>80% bio-based**

[10] Vert, M., Doi, Y., Hellwich, K.-H., et al. (2012) Terminology for biorelated polymers and applications (IUPAC Recommendations 2012), *Pure and Applied Chemistry*, Vol.84, No.2, pp.377–410

2.5 Oxo-(bio)degradable Materials

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.[11]

In 2018 the European Commission announced that "a process to restrict the use of oxo-plastics in the EU will be started" and have officially stated that oxo-biodegradable plastic packaging shall not be considered as biodegradable. The Single-Use Plastics Directive also explicitly places a ban on all products made from oxo-degradable plastic and Member States are required to comply with this by 3rd July 2021. These materials will therefore not be included in the scope of this report.

2.6 Standards and Certifications

The following provides a brief overview of how definitions are tested and certified in practice.

2.6.1 Controlled Environments

For the purposes of testing and standardisation it is important to distinguish between controlled and uncontrolled environments. Industrial compositing can be considered a controlled environment as all of the key parameters that encourage biodegradation can kept at strict levels and it is a recognised form of waste management. Home composting can be, to a lesser extent, considered controlled as the key parameters can also be influenced – the systems and practice in home composting is discussed further in Section 8.1

2.6.2 Industrial Composting

There are currently two European standards for biodegradation in industrial composting and anaerobic digestion: EN 13432 has been in place since 2000 and is linked to the European Directive on Packaging and Packaging Waste (94/62/EC) where meeting the standard presumes conformity with the essential requirements in the Directive. EN

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

14995 contains identical criteria, but its scope is for other non-packaging plastic products.

The EN 13432 standard outlines both specifications for industrial composting and anaerobic digestion. The standard has three primary requirements:

1) **Disintegration:** the sample must contain no more than 10% of material fragments larger than 2mm after 12 weeks (5 weeks in anaerobic digestion) of being maintained under test composting conditions with other organic wastes.
2) **Biodegradability:** the sample must biodegrade to carbon dioxide by at least 90% compared to a control or reference material (often cellulose) within **6 months** under test composting conditions (50% after two months in anaerobic digestion)
3) **Quality compost:** the sample must not have any negative effect on the composting process.

The requirement for 50% biodegradation in AD reflects the shorter processing time of AD, however, this is caveated with the following requirement:

> *"The lower percentage of biodegradation is justified because in all commercially available biogasification plants the process scheme provides a* ***short second aerobic stabilization phase in which the biodegradation can further continue****."*

The relevance and importance of this is discussed further in Section 4.1 and the standard itself is discussed in detail in Section 5.0.

The most commonly used certifications for industrial composting within the EU are OK compost from TUV Austria, the seedling logo which is licenced by European Bioplastics and the DIN Geprüft from Din Certco. These also certify compliance with EN 13432. Occasionally the logo from the Biodegradable Plastics Institute (BPI) is found on products in the EU, but this is primarily for the US market and signifies conformity with ASTM D6400 – the American equivalent of EN 13432 which has almost identical requirements. The labels associated with each of the certifications are as shown in Figure 4.

More comprehensive discussion of EN 13432 including some of the limitations and criticism that have been levelled at it can be found in Section 5.0

Figure 4 - Industrial Composting Certifications Associated with EN 13432

Source: TUV Austria, European Bioplastics, Din Certco

2.6.2.1 Home Composting

The standards and certifications for home composting are discussed in detail in Section 8.0 where this study investigates the validity of this as a waste treatment method for plastics.

2.6.3 Uncontrolled Environments

Uncontrolled environments are those where the there is no waste management system in place and the item ends up there either through littering or as an inherent part of the product use. These environments should ideally not be considered legitimate end destinations for any material regardless of whether it will biodegrade—there may be some instance where this is unavoidable or alternatives result in worse environmental impacts. This is why there is a great deal of work ongoing to validate standards in these environments.

2.6.3.1 Marine Environment

The marine environment is a particularly difficult environment to develop standards for.

An American standard – ASTM D7081 – previously existed for biodegradation in the marine environment, however this standard was withdrawn in 2014 and has yet to be replaced[12]. Work has been ongoing for several years to develop a new marine standard, however the marine environment is actually a whole host of different environments with varying temperatures and organic life so it is very difficult to create the large number of test methods that can accurately imitate these environments— it is almost impossible to determine a standard test method that works at the same time for surface waters, coastal sediments and the deep sea, for example. ASTM D7081 only focused on surface waters, but plastics are likely to move throughout the depths of the oceans and into sediments—testing and certification to this standard is still being carried out despite it not being representative of reality.

A further complication when trying to develop a standard for the marine environment is deciding a time frame in which it is suitable for a plastic to reside in the ocean. The level of risk to wildlife, from either entanglement or ingestion, would relate specifically to this timeframe. A method for qualifying this risk has yet to be determined and therefore there is no way to arrive at a suitable timeframe. This is in marked contrast to industrial composting standards which do not use a time threshold based on environmental risk, but are tuned to the composting/AD process. The concept of 'inherent biodegradability' that is used in composting standards to verify that is will *eventually* biodegrade is likely to be insufficient in the open environment.

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[12] *ASTM D7081-05: Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment,* accessed 9 November 2018, https://www.astm.org/DATABASE.CART/WITHDRAWN/D7081.htm

2.6.3.2 Soil and Mulch Films

In 2018 a standard for biodegradable mulch films was introduced – EN 17033[13]. The standard requires a minimum of 90% biodegradation within two years at a test temperature of 25°C, and includes various eco-toxicity tests and a restriction on the use of hazardous substances. Although the standard supposedly confirms biodegradation in soil, it would be incorrect to use it for anything other than mulch films as it is product specific. It is, however, identical to the criteria specified in TUV Austria's OK Biodegradable Soil certification which is aimed at any products.

There is currently no European wide standard for the biodegradation of other plastic products in soil, however the Belgian "product standards for compostable and biodegradable materials" and the French NF U 52-001[14] standard include specifications for these types of products. These align with TUV Austria's OK Biodegradable Soil certification with the primary condition being 90% biodegradation over 2 years at a temperature of 18°C – 30°C.

2.6.4 Certifications

Despite a lack of European standards for many environments, there are several independent certification bodies who certify for biodegradation in different environments. The two most common certification bodies within Europe are TUV Austria and Din Certco; these are shown in Figure 5. TUV Austria provide certifications for industrial composting, home composting, soil, marine and fresh water environments. Din Certco provide certifications for industrial and home composting and soil.

As described previously the marine certification is based on the now withdrawn ASTM D7081 standard (there has never been a European equivalent). The test requires biodegradation within 6 months at a temperature of 30 ± 2°C—and whilst this is a lab test and thus not designed to directly replicate the marine environment, this temperature is far higher than the majority of the sea surface waters and this becomes even more so with increased depth. It is unclear what the time threshold would have to be if the temperature were reduced to a level that is more representative. The certification does, however, recognise the risk of using this functionality as a marketing tool that might promote littering; it has therefore prohibited the use and marketing of this label on products unless the product has "…a function in the same environment (sea water) where they are meant to biodegrade" (fishing gear for example). It is not a certification that should be used as a way of mitigating the impact of land-based litter than may find its way into the marine environment. Several material suppliers openly

[13] BS EN 17033:2018 – Plastics. Biodegradable mulch films for use in agriculture and horticulture. Requirements and test methods.

[14] https://www.boutique.afnor.org/standard/nf-u52-001/biodegradable-materials-for-use-in-agriculture-and-horticulture-mulching-products-requirements-and-test-methods/article/633557/fa136042

promote that their material has passed this certification (including Lenzing[15] and Kaneka[16] which both show it adjacent to products which would not be suitable for promotion i.e. clothing and bags respectively) although there is no evidence to suggest that any products themselves display this label in contravention of rules and TUV Austria devote resources to police conformance.

Figure 5: European Certifications for Biodegradable Plastics

Labels	Reference Standard	Test Conditions (if different from ref std.)	Biodeg Test Threshold
HOME OK compost TÜV AUSTRIA HOME; HOME COMPOSTABLE DIN Geprüft	EN 13432	Ambient temperature (20°C – 30°C)	90% in 12 months
SOIL OK biodegradable TÜV AUSTRIA SOIL; BIODEGRADABLE IN SOIL DIN Geprüft	ISO 17556[1]		90% in 2 years[4]
MARINE OK biodegradable TÜV AUSTRIA MARINE	ASTM D7081 (withdrawn)		90% in 6 months
WATER OK biodegradable TÜV AUSTRIA WATER	EN 14987[2]	20°C and 25°C	90% in 56 days

Notes:
1. *This is the test method for aerobic biodegradability of plastics in soil.*
2. *This is the test method for biodegradability of plastics in waste water treatment plants—used as a proxy for fresh water environments.*
3. *Test threshold the same as EN 13432*
4. *Test threshold the same as EN 17033*

[15] https://sustainability.lenzing.com/issue-03-2018/
[16] https://www.kaneka.co.jp/en/business/material/nbd_001.html

3.0 The EU Biodegradable Plastics Market

The following section summarises the current knowledge around the most common applications and market in the EU for biodegradable plastics. It is fair to say that overall the data is limited, often conflicting and lacking in detail. This is a result of the market being relatively new and small compared with the overall plastics market. The raw biodegradable polymer market is dominated by a few larger manufactures, so data on production and sales is commercially sensitive. Identifying exact quantities of specific *products* on the market is even more challenging. This is because some applications may account for a few hundred or thousand tonnes per year which could easily fluctuate as a result of small changes, such as a factory closing, a feedstock shortage or even a customer buying more or less product in a particular year. It is clear, however, that the biodegradable market for packaging, and in particular single use bags, is the strongest and most likely to increase over the coming years.

It is important to highlight that the market is usually characterised under the term *biodegradable plastics* rather than *compostable plastics*. These terms are used in the report where the original data source refers to them as such. In reality, the vast majority of the biodegradable plastic market is likely to also be classed as *compostable plastic,* and would be marketed as such. From the perspective of certifications, 99% of certified biodegradable products are either industrial or home compostable.

3.1 Scope

The scope of this overview is restricted to consumer plastic products and packaging. This is a broad category that is best characterised by identifying products that are not included; these are any industrial or building products and other commercial products such as fishing equipment.

The only exception to this is in this section of the report addressing the market, as agricultural mulch films are included. They are expected to be a relatively large market sector, but these are not included throughout the rest of the report.

3.2 Common Biodegradable Polymers

There are many types of biodegradable polymers on the market, with varying degrees of biodegradability. They each have their own unique properties, such as appearance, water and oxygen barrier properties, heat resistance and sealability. Polymers are often combined to produce composite materials with improved properties. Some of the properties of common biodegradable plastics are as outlined in Table 2, as well as their level of biodegradability.

Most commercially available compostable plastics are thermoplastics, which mean they could, in theory, be melted and reused. Although they can theoretically be recycled, it is necessary to get a completely pure waste stream which is very challenging with current waste infrastructure.

Table 2: Properties of Biodegradable Plastics[17]

Plastic type	Properties
PLA	• Brittle • Clear • Generally suitable for food contact applications • Can also be used as a foam • Industrially compostable. Needs high temperatures to degrade therefore not biodegradable in other environments.[18]
Starch blends	• Wide range of different properties • Can be used as a foam • Difficult to get food contact approved, however some are, e.g. Mater-Bi[19] • Often industrially and home compostable, dependent on the blend
Cellulose Acetate	• Rigid • Some types certified according to EN 13432[20], although it is not all
Cellulose (regenerated)	• Clear • Thin flexible films (cellophane) and non-wovens • Thought to be biodegradable in water, and industrially compostable
Polyesters (PBAT, PBS(A), PCL)	• Various properties • Can replace PP or LDPE • Some flexible and very tough • Some grades food contact approved • Normally found in blends
PHAs	• Various properties • Not used often commercially, normally in blends • Industrially and home compostable, thought to be biodegradable in soil and marine environments.
Composites	• Two or more materials (normally resin and fibre) • Improved mechanical and physical properties • Biodegradability depends on the constituent products

[17] CE Delft (2017) Biobased Plastics in a Circular Economy: Policy Suggestions
[18] Food Standards Agency (2010) *Biobased materials used in food contact applications: an assessment of the migration potential*, December 2010, https://www.food.gov.uk/sites/default/files/media/document/a03070.pdf
[19] Mater-Bi Packaging Solutions: Biodegradable and Compostable for Food and Non-food Applications, http://materbi.com/en/wp-content/uploads/sites/2/2016/05/scheda-packaging_EN_TUV_LR-.pdf
[20] *Biograde® › FKuR*

3.2.1 Polylactic Acid (PLA)

Polylactic acid (PLA) is 100% bio-based[21] and is one of the most common biodegradable plastics on the market[22]. It is industrially compostable, but does not conventionally biodegrade in other environments, due to the high temperatures required.[23] PLA has many mechanical and optical properties that make it a good substitute to conventional plastic, and make it suitable for food packaging applications. It has been proven to be 'Generally Recognized As Safe' by scientists following guidelines from the US Food and Drug Administration.[24] Also, many brands of PLA have specifically been approved for food contact applications within Europe; for example, Natureworks PLA has been approved for direct contact with all aqueous, acidic and fatty foods below 60°C, and for acidic drinks served under 90°C.[25] It is used as both a rigid plastic product and as a film, however the films are relatively stiff compared to conventional films such as LDPE. It has low water barrier properties, which means that as a mono-layer material it is not well suited to products that require a long shelf life.[26]

3.2.2 Polyesters

After PLA, the most common biodegradable polyesters on the European market are polyesters, including polybutylene adipate terephthalate (PBAT), polycaprolactone (PCL) and polybutylene succinate (PBS).[27] These are primarily fossil-based, however bio-based PBS is also commercially available with up to 50% bio-based content.[28] They are often blended with other biodegradable plastics to improve their properties. For example, polyesters are often combined with PLA films to reduce the PLA's stiffness, or with

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[21] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929

[22] European Bioplastics (2018) Bioplastics Facts and Figures 2018

[23] Food Standards Agency (2010) *Biobased materials used in food contact applications: an assessment of the migration potential*, December 2010, https://www.food.gov.uk/sites/default/files/media/document/a03070.pdf

[24] Conn, R.E., Kolstad, J.J., Borzelleca, J.F., Dixler, D.S., Filer, L.J., Ladu, B.N., and Pariza, M.W. (1995) Safety assessment of polylactide (PLA) for use as a food-contact polymer, *Food and Chemical Toxicology*, Vol.33, No.4, pp.273–283

[25] Food Standards Agency (2010) *Biobased materials used in food contact applications: an assessment of the migration potential*, December 2010, https://www.food.gov.uk/sites/default/files/media/document/a03070.pdf

[26] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929

[27] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929

[28] Molenveld, K. (2015) *Biobased Packaging Catalogue*, 2015

starch-based films to improve water resistance and tear strength. Polyesters are also often used as a coating for paperboard.[29]

3.2.3 Polyhydroxyalkanoates (PHA)

Polyhydroxyalkanoates (PHAs) are a wide range of polymers - including polyhydroxybutyrate (PHB), polyhydroxyvalerate (PHV) and polyhydroxyhecanoate (PHH) - that are all very new to the commercial market. They are 100% bio-based and show potential to degrade in environments less aggressive than industrial composters, for example in soil or marine water.[30] They have many promising properties, for example they are hydrophobic, can be used at a high temperature and are extremely versatile.[31] Some PHAs are food contact approved, however this is on a product specific basis.[32] It is thought that PHAs haven't broken into the packaging market due to their high cost.

3.2.4 Starch Blends

Starch blends are complex mixtures of starch with other biodegradable polymers (often fossil-based biodegradables, e.g. BASF's Ecoflex®). The blending of the starch with these other polymers can improve properties such as water resistance and flexibility.[33] There is a very wide variety of different starch blends on the market that all lend themselves well to different applications, and different levels of compostability. Due to their high flexibility and translucence, they are well suited to carrier bags and fruit and vegetable bags. They are also often used in food waste caddy liners[34]. It is generally difficult to get food contact approval for starch blends, however there are some exceptions to this rule, for example Mater-Bi.[35] Rigid or foamed starch-based plastics also exist, and can be used, for example, as fruit trays, service ware or loose fill foam packaging.[36]

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[29] Molenveld, K. (2015) *Biobased Packaging Catalogue*, 2015
[30] ibid
[31] Food Standards Agency (2010) *Biobased materials used in food contact applications: an assessment of the migration potential*, December 2010, https://www.food.gov.uk/sites/default/files/media/document/a03070.pdf
[32] Molenveld, K. (2015) *Biobased Packaging Catalogue*, 2015
[33] Food Standards Agency (2010) *Biobased materials used in food contact applications: an assessment of the migration potential*, December 2010, https://www.food.gov.uk/sites/default/files/media/document/a03070.pdf
[34] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929
[35] Mater-Bi Packaging Solutions: Biodegradable and Compostable for Food and Non-food Applications, http://materbi.com/en/wp-content/uploads/sites/2/2016/05/scheda-packaging_EN_TUV_LR-.pdf
[36] ibid

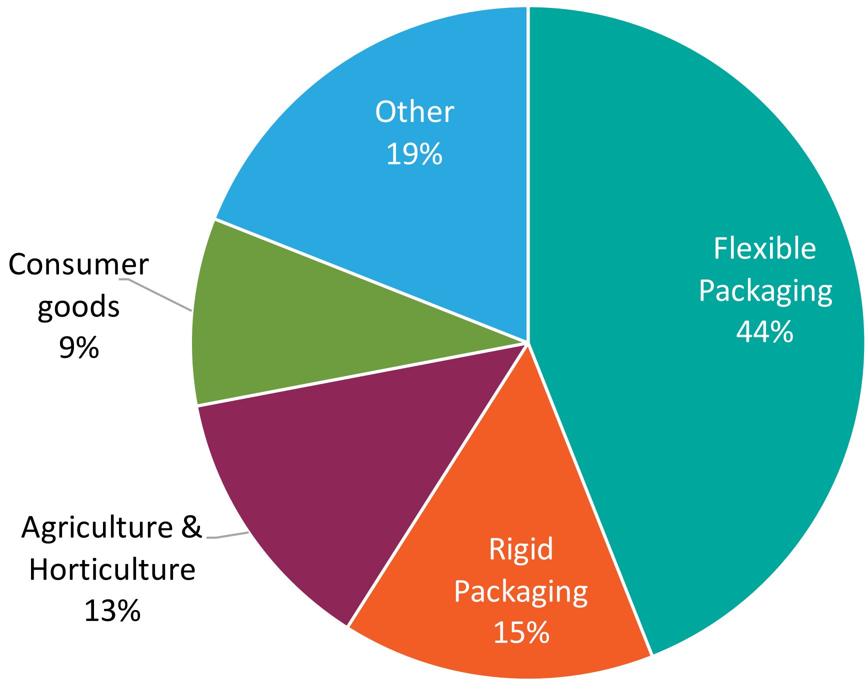
3.3 Applications

3.3.1 Common Market Segments

Biodegradable plastics are found in many different market segments, including packaging, textiles, automotive, consumer goods, agriculture, horticulture, construction and electronics. There is data published on the amount of biodegradable plastic within each market segment. This data, however, does not state the environment in which this plastic is expected to biodegrade in, instead it refers to all biodegradable plastics. For the market segments that are of relevance to this project - packaging, consumer good and agriculture - it almost all consists of either compostable or soil biodegradable plastics (for mulch films), as shown in Appendix A.1.0.

As shown in Figure 6, packaging is the leading sector for biodegradable plastics. This is also the dominant section within Europe for the conventional plastics market. Biodegradable plastics are also used frequently as consumer goods and in agriculture – often as mulch films.

Figure 6: Applications by market segment for biodegradable plastics, 2018[37]



[37] European Bioplastics (2018) Bioplastics Facts and Figures 2018

3.3.1.1 Packaging

As shown, packaging takes 59% of the market share of biodegradable plastics. This includes both flexible and rigid types, with flexible packaging being the most common, taking over 44% of the market. Biodegradable plastics are predominantly used in packaging as the products often have a short functional life, i.e. are single-use.

It should be noted that in this report, packaging includes carrier bags and biowaste bags, which are not packaging according to the definition under Article 3 of the Packaging and Packaging Waste Directive. Where data for these products is available separately it will be clearly stated.

The product with the largest share of the European biodegradable plastics market is the biobags used to collect organic waste from households. Many of these are industrially compostable in accordance with EN 13432, as well as being certified as home compostable.

There has also been an increasing trend in recent years to move towards industrially compostable bags for fruit and vegetables, both self-service and prepacked. It has been shown that for some compostable plastics, when used as fruit and vegetable bags, they can offer advantages over conventional plastics; for example, PLA's high breathability can extend shelf life of perishable food, thus minimising food waste.[38] These characteristics, however, can be disadvantageous in other circumstances, for example the breathability of PLA reduces its suitability as a beverage bottle (although coatings could be used to improve this).

The most common compostable plastics that are used for packaging are PLA and starch-based plastics, and their share of the market is discussed further in Section 3.5.4. Shown in Table 3 is an outline of the alternatives to conventional plastic used in packaging, and their most commonly associated applications.

[38] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929

Table 3: Compostable alternatives to conventional plastics including their applications[39]

Conventional Plastic	Application	Biodegradable alternative
Polyethylene (PE)	Films and bottles	Starch blends PLA blends PHA PHA blends
Polypropylene (PP)	Films, bottles and thermoformed products	PHA PHA blends PLA blends
Polystyrene (PS)	Hard thermoformed packaging and foam	PLA (foam, films and hard packaging) Cellulose (pulp trays) Starch blends
Polyethylene terephthalate (PET)	Bottles, trays and blister packs	PLA

The Directive on the reduction of the impact of certain plastic products on the environment (commonly referred to as the Single Use Plastics (SUP) Directive) [40] will have a large impact on plastic packaging in the EU. It includes specific measures to reduce the consumption of some products such as takeaway cups and single use bottles, and ban other products, such as single use cutlery. The intent is that biodegradable and bio-based plastics are considered to be 'plastic' under the SUP Directive and fully covered by its provisions. The issue of (marine) biodegradable plastics will be looked at again in the context of the 2027 evaluation of the Directive.

Although under the Directive compostable plastics are currently treated the same way as conventional plastics, in some countries have taken an alternative approach by banning certain types of plastic packaging, but with compostable plastics as an exemption – vegetable bags in France for example (see section 3.6.1.1 for more detail). Given that the Directive targets plastics that are being littered – specifically those that end up in the

[39] Molenveld, K. (2015) Biobased Packaging Catalogue, 2015
[40] (2019) Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (Text with EEA relevance), 155

marine environment, compostable plastic products are unlikely to be considered a suitable alternative in future revisions.

Food Packaging

Compostable plastics are most often used in food contact applications, as these can easily become contaminated with food and therefore can make traditional dry recycling challenging. If the packaging is compostable, it can theoretically be processed alongside this organic contamination in a composting facility. This may have particular relevance for on-the-go products, and for packaging where cleaning prior to collection isn't an option.

One example that accounts for a large proportion of the compostable plastic market share is on-the-go packaging such as deli containers, drinks cups and sandwich boxes. As outlined above, these can, when waste collection operators instruct households to do so, be disposed of with food-/ biowaste in organic collections. However, it should be kept in mind that the appropriate waste stream may not be available outside of the household, as organic collections are not widespread in workplaces or public spaces. However, in the EU, following the 2018 revision of waste legislation, Member States will have the obligation to put separate collection of bio-waste in place by 2023.

Through discussion with experts, it has been established that there is one particular situation where there is the potential to use compostable packaging: closed systems, for example at events or within hospitality (e.g. in a fast food outlet), where it has been prearranged that all packaging will be compostable and there is a suitable waste collector in place.[41] However, where using reusable products or packaging is feasible, this will generally be preferable over the use of single use/ disposable packaging.

There are strict EU regulations regarding the safety requirements for materials in contact with food[42] which set out the general principles of safety and inertness for all Food Contact Materials (FCMs) These standards are the same for conventional and biodegradable plastics.

Non-food packaging

There are fewer examples of non-food applications from compostable plastics. Through discussions with stakeholders, one application that was identified where compostable plastics could be appropriate was in pallet wrap plastic.[43] If this plastic was replaced with a compostable alternative there would be an opportunity to collect the packaging in a segregated manner. Some stakeholders are sceptical of using compostable plastics for this purpose, as several additional labels are added along the supply chain which would potentially render the product non-compostable.

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[41] European Bioplastics (2018) Biodegradable Plastics in the Single-Use Context

[42] Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food

[43] Interview with Charlie Trousdell, Independent Consultant

Another non-food packaging application is mailshot packaging, which are traditionally made from polyethylene. These bags could be replaced with a compostable plastic alternative, and subsequently used in the household as food caddy liners.[44]

Loose fill starch packaging is another example where biodegradable or compostable plastics are used. This packaging is traditionally polystyrene, due to its physical properties and low price, which is difficult to recycle.

It is also arguable that unless these types of packaging were food contaminated (which is unlikely) then it could easily be aggregated together and recycled—this is regularly undertaken for other plastic films at industrial sites that can collect enough clean films together to make recycling viable.

3.3.1.2 Consumer Goods

As biodegradable plastics have a wide range of properties they can, in theory, replace a wide range of consumer goods that would typically be made with conventional plastic. Some have particular properties that lend themselves well to specific applications, such as improved breathability; a function particularly important in personal hygiene products such as female sanitary products, nappies and disposable gloves.

It is important to note that biodegradable plastics are not necessarily beneficial for products that require a long functional life.

3.3.1.3 Agriculture and Horticulture

Biodegradable plastics are often used in agriculture as mulch film and bale wrap. They can potentially offer advantages over other conventional plastics; however, this depends largely on the biodegradability of the product.

Traditionally, mulch films have to be retrieved from the field separately from organic matter; a task that is both laborious and costly. The theory behind biodegradable mulch films, however, is that they do not need to be separated from organic matter but can simply be ploughed back into the soil after use, and will biodegrade in the soil environment. They are often thin, and have a corresponding standard for their biodegradation – see section 2.6.3.2.

The biodegradable mulch film market has grown significantly in the past five years – it was reported to take 3% of the total global market for mulch films in 2016 and 13% in 2018. It is thought that this is due to the savings that farmers can make by not having to remove it. In Norway, for example, it is expected that 75-80% of mulch films are biodegradable.[45]

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[44] *Material concerns: what can take the place of polywrap? | PrintWeek*, accessed 24 June 2019, https://www.printweek.com/print-week/feature/1165797/material-concerns-what-can-take-the-place-of-polywrap

[45] Torfinn Belbo (2018) *ZERO-notat: Fornybar landbruksplast*, Report for ZERO, August 2018, https://zero.no/wp-content/uploads/2018/08/ZERO-notat-fornybar-landbruksplast.pdf

Biodegradable plastics are also used in horticulture, for example as pots that can be planted directly into the soil. It is not clear how widespread this use is, however it is expected to be a very small proportion of the market.

3.3.2 Most Common Applications

Little data is available on the quantity of each end product on the market, as the data is often commercially sensitive. As such, it is not possible to determine a completely accurate and up to date, ordered list of the most common applications and the quantities on the market.

The Nova Institute reported in 2015 that the top applications by weight sold, in order, were shopping bags, biowaste bags, disposable tableware, rigid packaging, other flexible packaging (not including shopping or biowaste bags), consumer goods, fibre products and agricultural and horticultural applications.[46] This is the only data available on EU sales by application, but due to the nature of the market—several niche applications—there is a lack of specific detail.

Through analysing both data on the products that are certified (from 2019) and the proportion of product groups on the market (from 2015), the ten most common applications on the European market have been identified - outlined in Table 4.

For carrier bags, biowaste bags, rigid packaging, other flexible packaging and agricultural films, data was available on the proportion of these products on the EU market in 2015.[47] This allowed calculation of an indicative quantity on the market - using the total market size, as calculated in this report.

The other applications listed in the table were determined through analysing the share of the individual product certifications. This is as a proportion of product certifications put on the market, rather than as a proportion of financial value or actual tonnes on the market. The indicative values have been calculated by looking at the share of product certifications from TUV Austria – see Section 3.4 for more details. It should be recognised that this only represents certified products; it is expected, however, that this is largely representative of the market as a whole as none of the major manufactures sell uncertified *material* even if the end product is not certified (which it should be).

The list of ten most common applications has also been verified through discussions with industry stakeholders and a review of the limited literature available.

As shown, carrier bags and biowaste bags combined make up almost 60% of the certified product market by number of certifications in 2019, and 68% of the mass of product found on the market in 2015. The main disparity between certification and quality is in

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[46] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*

[47] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*

rigid packaging compared with flexible packaging whose relative proportions are reversed. It is unclear why this is the case other than the likelihood that there are fewer manufactures of rigid packaging and therefore fewer individual products overall.

There is also a large number of certified compostable single use cutlery items and plates on the European market. These products will be banned under the SUP Directive and therefore the quantity on the market is expected to decrease to near-nothing once the restrictions on placing on the market enter into force from July 2021

Table 4: Most common applications of certified compostable plastics on the European market

Application	**Indicative quantity on EU market in 2015, ktonnes[4]**	Share of product certifications[5]
Carrier bags	65 – 74	29%
Biowaste bags	54 – 62	28%
Rigid packaging (food and non-food)	16 – 18	4%
Other flexible packaging (food and non-food, not incl. carrier or biowaste bags)	8 – 9	12%
Agricultural films	7 - 8	2%
Single use trays and plates[1]	*Data not disaggregated: Disposable tableware (incl. trays, plates, cups and cutlery) 10 - 12*	6%
Single use cups[2]		4%
Single use cutlery[3]		2%
Bags for loose products (vegetables and other)	*Unknown*	3%
Coffee pads, filters and capsules	*Unknown*	3%

Notes:

1. Plates will be banned across Europe under the SUP Directive Article 5
2. May be subject to national bans or restrictions under SUP Directive Article 4
3. Will be banned across Europe under the SUP Directive Article 5
4. Calculated using total quantity on EU market as calculated within this report, plus proportion of EU market data in 2015 – where available - from Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*
5. TUV Austria: Certified Products, as of 25 June 2019, http://www.tuv-at.be/certified-products/

3.4 Certified Biodegradable Products

It has not been possible thus far to determine absolute quantities of products that are certified, or to subsequently work out how much of the biodegradable plastic said to be on the European market holds a certification. Both TUV Austria and DIN Certco carry out regular auditing of their certifications to ensure the integrity of their labelling systems. Neither, however, are able or willing to provide any data around the extent to which they discover non-conformances.

When looking at certified products it is important to note that a particular raw material can be certified at production level, but once incorporated into a product it may not have the same compostable properties and cannot be certified—the final product in itself must be certified which can be implied if all component parts have also been certified. One example on the market within Europe is a storage unit made from Bio-on® PHA (a certified compostable material for some applications), however in order to create a durable product the material thickness requirement[48] means that it is unlikely that it could be certified as compostable (and arguably shouldn't be, as a supposedly durable product).[49] Despite this, it is still marketed as 'biodegradable'. This example demonstrates not only the need for certifications, but also how it is easy to—deliberately or otherwise—make claims that are not scientifically credible. It also shows the difficulty in accurately quantifying the proportion of certified products and there is no way of knowing how many products with these sorts of unverified claims exist on the EU market.

Through discussions with European Bioplastics it has been established that all raw material sold by their members is certified according to EN 13432. This accounts for a large share the market, with an estimated 84% of material (by mass) being produced by European Bioplastics members.[50] As outlined above this does not necessarily mean that products made from these materials are eligible for certification.

It has been possible to analyse the number of products that are certified by TUV Austria by product type (as described in Section 3.3.2). Further details on the methodology used to gather this data, as well as further data, is provided in Appendix A.1.0.

As shown in Figure 7, 60% of the certifications given by TUV Austria are for bags, with 49% of those bags shopping bags, and 46% bags for the collection of organic waste. 17% of certifications are for catering products, including trays, plates, cups, cutlery and coffee pods, filters and capsules amongst others. 17% of certified products are other packaging (i.e. not including bags), including food and non-food and rigid and flexible packaging. Agricultural, horticultural and garden products make up 3% of certified products, which includes mulch films, plant pots, clippers and landscaping covers. There are also 3% of products that are classed as miscellaneous items.

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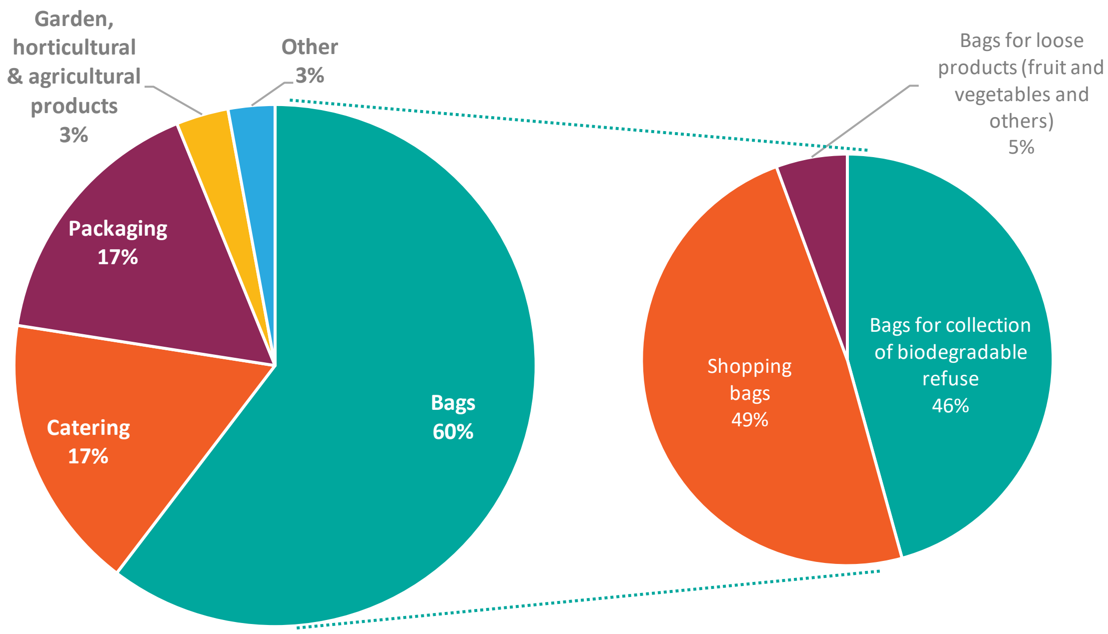
[48] The thickness or gauge of a material plays a very important part in whether a product can be certified as compostable. This is because of the required time limit that may be exceeded for thicker material despite the material being 'inherently biodegradable'.
[49] *Storage Componibili Bio by Kartell - Pink | Made In Design UK*, accessed 30 August 2019, https://www.madeindesign.co.uk/prod-componibili-bio-storage-3-drawers-natural-biodegradable-material-by-kartell-ref5970-ro.html
[50] Discussion with European Bioplastics

Figure 7: Share of TUV Austria certifications, by market area of the product



With regard to packaging, as highlighted in Section 2.0, the Packaging and Packaging Waste Directive (PPWD) necessitates that the Essential Requirements must be met. EN 13432 is the de facto standard used to prove conformity (compliance with the standard presumes compliance with the essential requirements)—certification is the best route to independently verifying compliance. However, the Essential Requirements are not well enforced and are currently subject to review in order to strengthen them.

3.5 Past and Current Quantity of Products on the Market

Due to commercial sensitivities; data is not readily available on the actual quantities of biodegradable products on the market. It was estimated in 2015 that 84% of the European raw polymer market is dominated by five key players: BASF, BIOTEC, FKuR, NatureWorks and Novamont.[51] Gathering data from end users is also challenging, as the end user market is made up of many small businesses, as well as larger organisations. The typical volume that converters deal with is 100-1,000 tonnes, and the typical volume

[51] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*

of people selling at consumer level is 10-100 tonnes.[52] This makes the market extremely difficult to trace.

Data is available, however, on the capacity of plastic production facilities. This gives an indication of the amount of biodegradable plastics on the global market. Although this data is currently considered the best source of market data for the biodegradable plastics industry, there are limitations to the data. The data has been reported annually by European Bioplastics for the past ten years, however the scope and data collecting methods have been refined over the years. Data prior to 2017 is not comparable with the current production capacity data reported for 2018.

There are two key reasons that production capacity may not be reached. The demand for biodegradable polymers has a significant influence on the quantity of polymer produced, and as such the production relies on the end market for biodegradable products. The production also depends heavily on the availability of feedstocks. For example, it was expected that large quantities of succinic acid – a feedstock used to produce PBS - would be available on the market in 2017, however the predicted amount has not been available for PBS production.[53]

3.5.1 Past Global Production Capacity

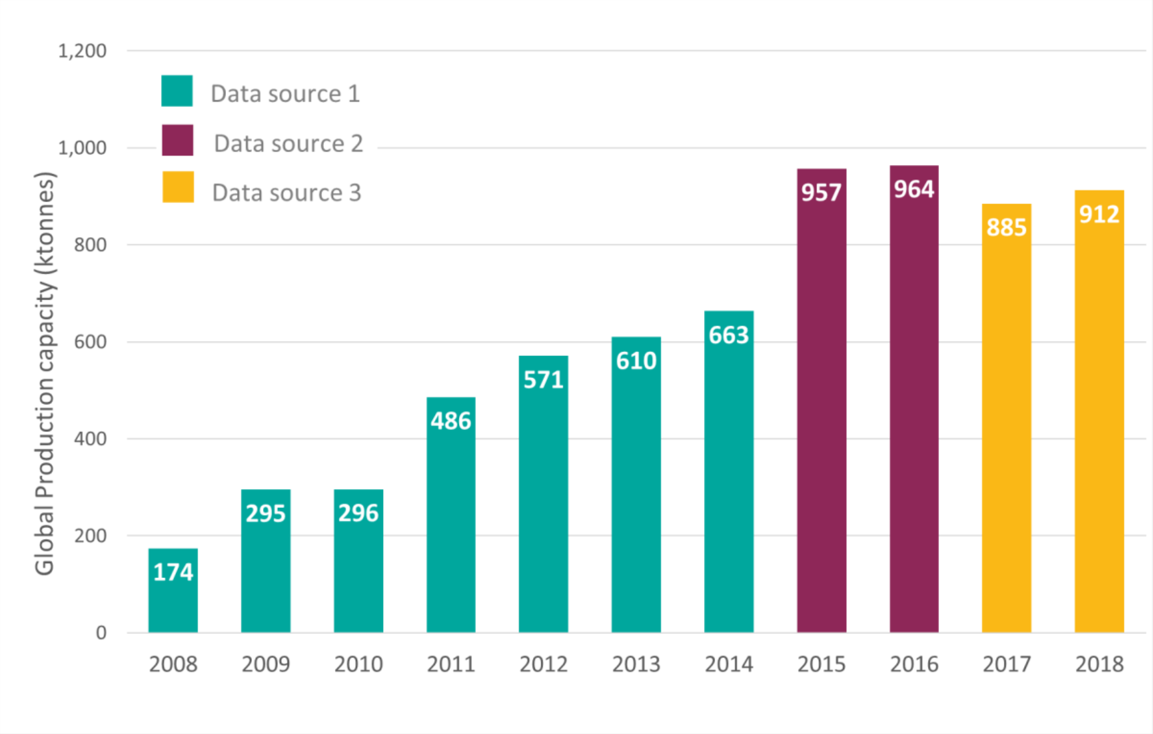
As outlined above, the production capacity data has been reported by European Bioplastics[54,55,56,57,58] for the past ten years, but each year is not wholly comparable. The annually reported predictions are as shown in Figure 8.

The source of data was changed to improve accuracy, so it is expected that the most recent data for 2017 and 2018 is the most reliable. This most recent comparable data shows there was a 3.05% increase in production capacity from 2017 to 2018. Through discussions with key stakeholders it has been determined that this increase has been fairly consistent since 2008, with an average annual increase of 3-4%.

[52] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*
[53] (2019) *Discussion with European Bioplastics*
[54] European Bioplastics (2010) *Bioplastics Facts and Figures 2010*, accessed 15 May 2019, http://www.plastemart.com/upload/literature/bioplastic-capacity-to-surpass-one-mln-ton-2011-biodegradable-polymers.asp
[55] European Bioplastics (2011) *Bioplastics Facts and Figures 2011*, accessed 15 May 2019, http://www.plastemart.com/upload/literature/europe-strong-bioplastic-growth-led-by-bio-polyethylene-terephthalate-pet.asp
[56] European Bioplastics (2013) Bioplastics Facts and Figures 2013
[57] European Bioplastics (2014) Bioplastics Facts and Figures 2014
[58] European Bioplastics (2017) Bioplastics facts and figures 2017

Figure 8: Reported global production capacity of biodegradable plastics, 2008 to 2018

Note that change in data sources and methodologies mean that no trend can be inferred between 2014 and 2017



3.5.1.1 European Share

The European share of the market is hard to predict due to commercial sensitivities. The Nova Institute estimated the quantity of polymers sold on the EU market in 2015 to be between 115-140kt, and the quantity of end products sold to be 100kt.[59]

There is little data available on how the European share of the market may have changed over the past ten years, it has been reported that Europe held 35-40% of the market value in 2016[60] and another source reported the share to be 55% in 2018[61], however it is not clear if these estimates are comparable, and indeed whether this reflects a real market share increase.

[59] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*

[60] *Biodegradable plastics - Global Market Outlook (2016-2022)*, accessed 17 May 2019, https://www.strategymrc.com/report/biodegradable-plastics-market

[61] (2018) *Demand For Biodegradable Plastics Expected To Surge*, accessed 18 June 2019, https://cleantechnica.com/2018/07/31/demand-for-biodegradable-plastics-expected-to-surge/

It is expected, however, that the European market has been growing more rapidly than other markets due to some legislative support and also growing environmental awareness amongst consumers.

One policy that is thought to have had an impact is the standardisation of recoverable mulch films. The standard – EN 13655 – was updated to include a minimum material thickness of 25µm to help prevent the films breaking up as they are removed from the field. Previous to this standard, conventional mulch films were often as low as 5 – 10µm, so to become compliant many film producers have had to increase their thickness significantly. As thickness increases so does cost, so it is expected that many producers have turned to biodegradables as they could be used at a lower thickness and were therefore more competitive.

Other national policies have also influenced the market, such as the banning of non-compostable plastic carrier bags in Italy and France. In 2017 the French Government enacted a ban on single-use conventional plastic bags, including those for fruit, vegetables and deli goods. Compostable plastic bags with an increasing proportion of bio-based feedstock were excluded from the ban and therefore there was a large scale move to compostable bags.

Prior to 2017, roughly 17 billion single-use bags were consumed each year in France. It is not clear at this stage how many of these bags have been replaced by compostable bags or simply prevented.

It is reported that in Italy, only 61% of single use bags were compostable in 2018, despite legislation requiring them all to be.[62]

3.5.2 Estimate of quantity on European Market

The global *production capacity* for all biodegradable plastics in 2018 was reported to be 912,000 tonnes[63]. Although this data is the most recent, and also expected to be the most accurate due to refined data collection methods and sources, there is no further data for this year that can be used to calculate European production capacity. The most recent data available was from 2016.

An estimation of the actual production tonnage as a proportion of global production capacity is calculated to be 70% in 2016. This was calculated by comparing the reported value of the global market to the value of the market that would be reached if facilities were producing at full capacity. The value of the market if facilities were running at full

[62] Arcelli, P. La filiera dei polimeri compostabili Dati 2018 – Evoluzioni attese
[63] European Bioplastics (2018) Bioplastics Facts and Figures 2018

capacity was calculated using the price of biodegradable plastics per tonne in 2016[64], and the percentage of global production capacity by plastic type in 2016[65].

It was reported that globally, in 2018, 59% of the end products made are packaging, 9% consumer goods and a further 13% for agricultural and horticultural purposes[66]. Although there are reported estimates for 2016, this proportional split is expected to be much more reliable and thus has been used rather than the 2016 data. This is a limitation to this analysis; however, literature suggests there have been no significant relative increases in the proportion of scope or non-scope products. It has also been assumed that the product share on the market within Europe is the same as the product share globally.

In this work it is assumed that the majority of biodegradable products within the agriculture and horticulture market area are in scope, either as they are mulch films or consumer goods. As such, it is estimated that 81% of biodegradable polymers produced are used for products within scope of this report.

Europe held 35-40% of the biodegradable plastics market in 2016[67].

The global production capacity for all biodegradable plastics in 2016 was reported to be 964,000 tonnes[68]. This suggests that there were up to 175,000-200,000 tonnes of scope products on the European market in 2016. The methodology for producing this estimate is as shown in Figure 9.

To verify this result, the total market value in Europe was used alongside the quantity of each plastic type expected to be on the market to calculate a "price per tonne" value for 2016. This was compared with the known prices for polymers, as published by Wageningen Food and Bio-based Research[69]. It was found that this methodology gives an appropriate price per tonne value, and thus gives a reasonable estimate of the market value in Europe.

The figure is also in agreement with other information quoted from stakeholders.

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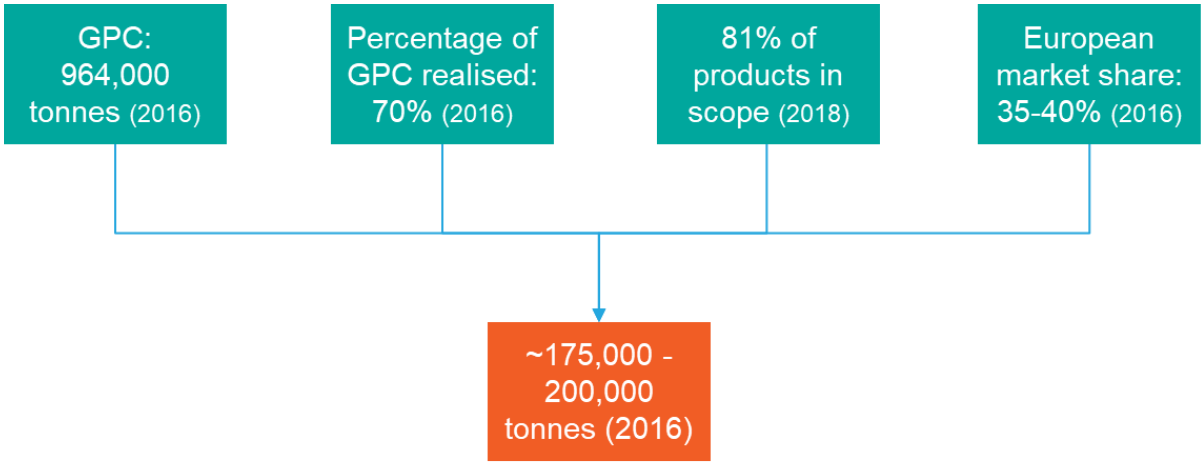
[64] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929
[65] European Bioplastics (2017) Bioplastics facts and figures 2017
[66] European Bioplastics (2018) Bioplastics Facts and Figures 2018
[67] *Biodegradable plastics - Global Market Outlook (2016-2022)*, accessed 17 May 2019, https://www.strategymrc.com/report/biodegradable-plastics-market
[68] European Bioplastics (2017) Bioplastics facts and figures 2017
[69] FBR BP Biorefinery & Sustainable Value Chains, FBR Sustainable Chemistry & Technology, Biobased Products, van den Oever, M., Molenveld, K., van der Zee, M., and Bos, H. (2017) *Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands*, Report for Wageningen, 2017, http://library.wur.nl/WebQuery/wurpubs/519929

Figure 9: Tonnes of scope biodegradable plastic products on the European market in 2016



3.5.3 Comparisons with the Conventional Plastics Market

The quantity of in-scope end products sold in Europe, including both conventional and biodegradable plastics, was reported to be 35 million tonnes in 2016[70]. This means that biodegradable plastics make up approximately 0.6% of the in-scope plastics market in Europe; a relatively small market share.

Studies at nation-level are not common, however a study was recently carried out focussing on biodegradable and/or bio-based products on the Norwegian market. It was expected that 3% of all plastic packaging was either bio-based or biodegradable. Assuming a similar split in Norway to Europe as a whole[71], this indicates that approximately 1.3% of all plastic packaging is biodegradable. The report also states that between 0.8 - 1.2% of plastic products in agriculture and horticulture in Norway were biodegradable[72].

There has also been a study carried out within the UK for the Biomass Biorefinery Network, predicting that approximately 8,000 tonnes of biodegradable, bio-based plastics are currently on the UK market. It is unclear exactly how much plastic is on the UK market; however, it is predicted that there were approximately 5.2 million tonnes of plastic waste arisings in the UK in 2018[73]. This indicates that biodegradable plastics account for less than 1% of the market.

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[70] Plastics Europe (2016) *Plastics – the Facts 2016: An analysis of European plastics production, demand and waste data*, October 2016
[71] European Bioplastics (2018) Bioplastics Facts and Figures 2018
[72] Eunomia Research & Consulting (2018) *Bio-Based and Biodegradable Plastics*, forthcoming 2018
[73] Eunomia Research & Consulting (2018) *A Plastic Future – Plastics Consumption and Waste Management in the UK*, Report for WWF - UK, March 2018

3.5.4 Market by Geography within Europe

The Nova Institute reported on the end products sold on the market by application within several key companies in Europe. The proportional split of the market by country is as shown in Table 5.

As shown, some markets within Europe are much more advanced than others, primarily the Italian market, with 48% of all the biodegradable plastic products in the EU in 2015 being sold in Italy. This is likely to have shifted to some degree since 2015, due to other countries such as France introducing plastic bag legislation and thereby driving increased demand - as outlined in section 3.5.2. Discussions with the original author of the report from which this data has come from suggests that it is their view that the market has not shifted hugely over this time, however.

For context, whilst biodegradable plastics make up 0.6% of the European plastic market, in Italy this is around 1.6% in France and Germany it is around 0.3%.[74] This means that the concentration of biodegrade plastics was at least five times greater than any other EU country in 2015/16.

Table 5: EU sales proportion of biodegradable end products by geography and application, 2015[75]

	AT-DE-CH	BE-NL	FR	IT	SP	N-EU	UK-IE
Biowaste bags	26%	16%	10%	26%	2%	10%	11%
Shopping bags	3%	5%	3%	84%	-	3%	1%
Flexible packaging (excl. bio/shopping bags)	22%	22%	22%	22%	-	-	11%
Rigid packaging	56%	11%	-	22%	-	11%	-
Disposable tableware	33%	17%	-	33%	-	17%	-
Coated paper packaging	-	-	-	67%	-	33%	-
Agricultural and horticultural	25%	25%	25%	25%	-	-	-
Consumer goods	25%	25%	25%	25%	-	-	-
Fibres	33%	33%	0%	33%	-	-	-
Total	**20%**	**13%**	**7%**	**48%**	**1%**	**7%**	**5%**

[74] Based on approx. 6m tonnes plastic market in Italy, 4m tonnes in France and 12m tonnes in Germany and total biodegradable plastics market of 200,000 tonnes in 2015/16.

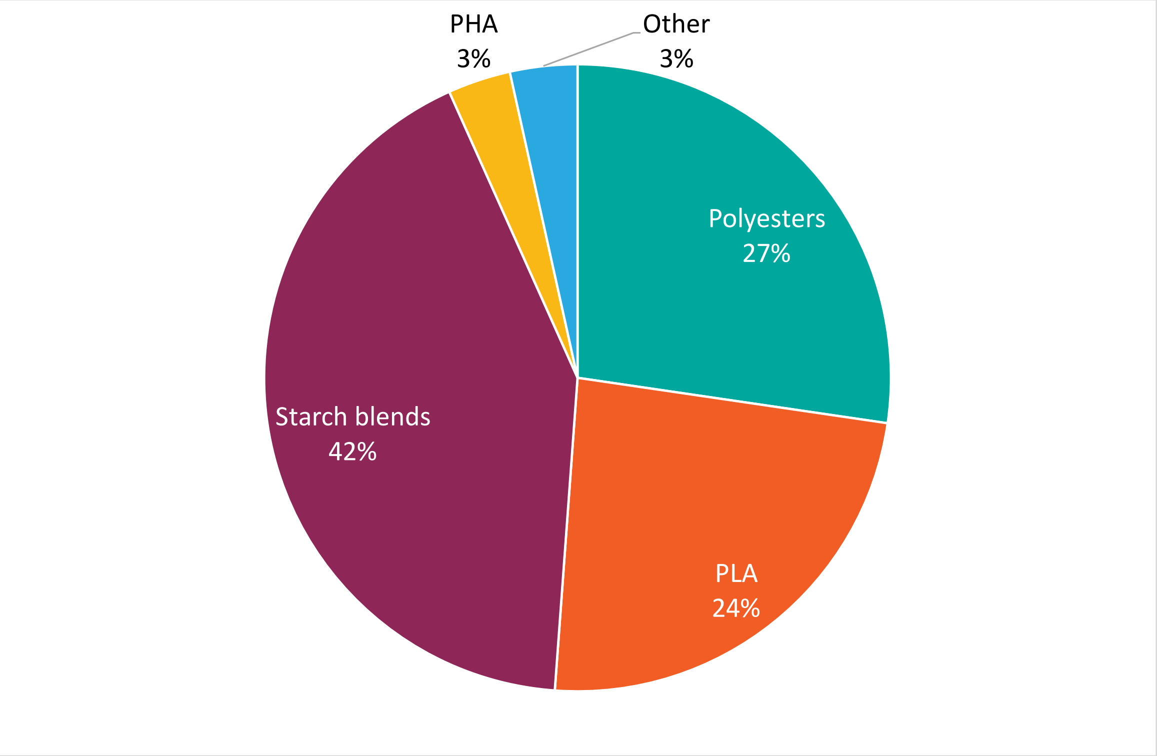
[75] Nova Institute (2016) *Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020*

3.5.5 Market Size by Plastic Type

The global market is currently dominated by three different groups of polymers; polyesters, PLA and starch blends. These polymers hold 27%, 24% and 42% of the market respectively – as shown in - with the remaining 7% split between PHA and other polymers.

Again, as previous studies have varied in source and scope, it is difficult to quantify how this has changed over the past ten years. It should be noted that production capacities of each polymer can fluctuate significantly if one production facility ceases or suspends production, which is not necessarily representative of what is being consumed.

Figure 10: Split of the global production capacity by polymer type, 2018[76]



The proportion of materials on the market that are bio or fossil based has been looked at, as shown in Figure 11.

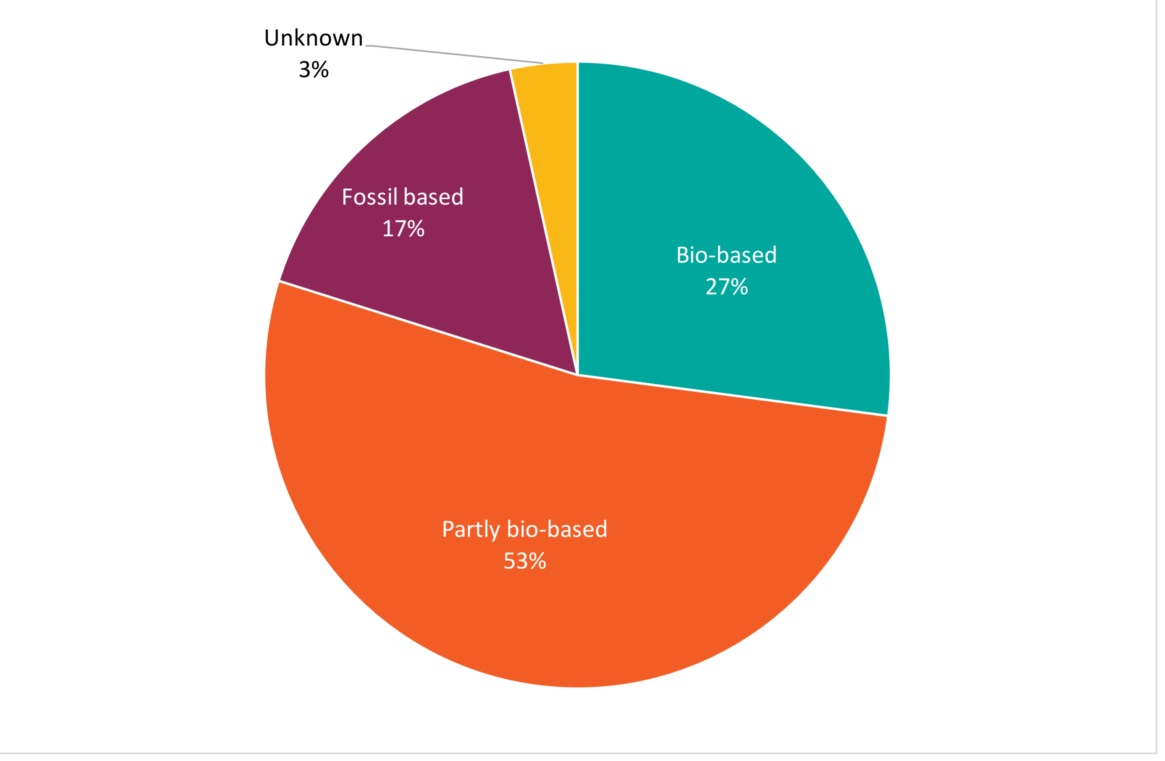
As shown, for the majority of materials on the market it has not been possible to determine the amount of bio-based feedstock in the material. This is largely due to the fact that there is no lower limit on the quantity of bio-based material in a polymer for it

[76] European Bioplastics (2018) Bioplastics Facts and Figures 2018

to be labelled as such, therefore even products that refer to themselves as bio-based can be upwards of 80% fossil-based content.

Typically, starch blends include between 25-100% of bio-based material. PBS – a common polyester – can be 50-100% fossil-based, whereby PBAT is currently 100% fossil-based. Bio-PBS is relatively new to the market, so it is expected that it's share is relatively small compared to the more established fossil-based PBS.

Figure 11: Proportion of products made from fossil or bio-based building blocks



3.6 Future Quantity of Products on the Market

3.6.1 Market Drivers

There are many potential market drivers, such as increased consumer pressure for materials to be 'environmentally friendly', policy measures and voluntary agreements. In the following section the political landscape in several focus countries will be detailed, in regards to compostable and biodegradable plastics. These countries have been identified as those that have, or are about to, enact policy that will heavily influence the biodegradable plastics market.

It should also be noted that there are targets and directives across the EU that will influence the market. The EU's Plastic Strategy[77] has the objective for all packaging placed on the EU market to be reusable or recyclable by 2030, although the term recyclable has not yet been defined. The Packaging and Packaging Waste Directive requires Members States to achieve a recycling target for plastics of 50% in 2025 and 55% by 2030. Plastics packaging that is composted may, under certain circumstances specified under article 6a of the Directive, and further specified in an implementing act on the calculation rules[78], be counted towards the recycling target.

The new Single-Use Plastics (SUP) Directive[79] commits the Commission to investigating the issues around biodegradability of plastics to determine whether they have a place in a circular economy. There is currently no exception for such materials in the SUP Directive. As stated previously, the Directive bans all products made from oxo-degradable plastic.

Appendix A.1.2 also provides an indicative scenario of what a business as usual growth may look like. However, it is clear that there are also many additional variables that will affect the market and therefore, this scenario should not be considered a forecast of the likely market.

3.6.1.1 France

Under the Energy Transition for Green Growth Act single use plastic bags thinner than 50 microns have been banned in France[80]. Home compostable bags are an exception to this decree and therefore a large-scale switch to home compostable plastics has been made. This applies to supermarket checkout bags, loose fruit and vegetable bags and packaging for mailshots, amongst others. The home compostable bags must meet the French standard for home composting – see section 2.6.2.1. They must also feature a bio-based content of at least 30%, with this planned to increase progressively to 60% in 2025.

This may have resulted in a significant increase to the compostable plastic market in France, however data is not available on how this has influenced the market, and as the transition has taken place it is unlikely to drive the market within France further.

Single use carrier bags have been gaining a lot of attention within Europe, with many countries enacting policies regarding their use. Some countries have enacted similar policies to France, for example Austria, who have also exempted compostable bags.[81] Other countries, however, have enacted policies to prevent single use bags altogether,

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[77] http://europa.eu/rapid/press-release_IP-18-5_en.htm
[78] Commission Implementing Decision (EU) 2019/665 of 17 April 2019 amending Decision 2005/270/EC establishing the formats relating to the database system pursuant to European Parliament and Council Directive 94/62/EC on packaging and packaging waste, (http://data.europa.eu/eli/dec_impl/2019/665/oj)
[79] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1562859783264&uri=CELEX:32019L0904
[80] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031044385&categorieLien=id
[81] The Paper Bag *Regulations in EU*, accessed 25 June 2019, https://www.thepaperbag.org/for-compliance-with-the-law/regulations-in-eu/

for example by charging a fee for any single use carrier bag and encouraging reusable bags.

3.6.1.2 Germany

Between 2005 and 2012 plastic packaging producers who made certified compostable packaging were exempt from the cost of collecting and recycling these wastes. Stakeholders raised concerns about the end-of-life treatment of this waste, with fears that it could contaminate recycling. In German regulations, biodegradable plastic packaging is not considered to be organic waste and, as a consequence, it is frequently incorrectly collected with recyclable waste – disrupting the recycling process.[82] As such, stakeholders were strongly opposed to the fee exemptions and they were subsequently removed.

The VerpackG Act does, however, stipulate that the systems collecting the waste fees are obliged to create incentives that encourage the use of recycled material or material from renewable sources for the production of packaging. This signals that bio-based and recycled materials may be recognised as equally feasible solutions to making packaging more sustainable. Germany already supports the use of certified bio-based and compostable bio-waste plastic bags for the collection of bio-waste in the Bio-waste Ordinance[83].

3.6.1.3 Italy

In 2011 the National Budget Law, and the National Environmental Law, ruled that thin single-use bags had to be certified industrially compostable in Italy. This includes checkout bags, as well as bags for fruit, vegetables and baked goods. Since 2018, customers have also been expected to pay for the compostable bags.[84] It is reported that only 61% of bags were certified as industrially compostable in 2018, despite this legislation. [85]

3.6.1.4 Netherlands

The Dutch EPR scheme – "The Packaging Waste Fund" – was established in 2013. Companies that place more than 50 tonnes of packaging on the market are liable for a charge that then contributes to the disposal of such waste. There are different tariffs associated with different materials, for example the charge for plastic per tonne is significantly higher than materials that are easier to recycle such as paper. The EPR scheme previously offered advantages to compostable plastics that comply with EN 13432. They had significant savings, as the fee was 2 cents per kg rather than the 64

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[82] International benchmark of support measures for bio-based products and their applicability in France, SYNTHESIS REPORT, Study undertaken for ADEME by: BIO BY DELOITTE and NOMADÉIS. (June 2015)
[83] https://www.european-bioplastics.org/germany-takes-important-step-to-support-bio-based-packaging/
[84] Povoledo, E. (2018) Biodegradable Bags Cause Outrage in Italy. (It's Not Really About Bags.), *The New York Times*
[85] Arcelli, P. La filiera dei polimeri compostabili Dati 2018 – Evoluzioni attese

cents per kg for conventional plastic. This exemption, however, is due to end in 2019, with the fee for compostable plastics being increased to match those of conventional plastics. The decision to end the exemption was made as industrial composting facilities did not want the additional plastic material, and monitoring of the biowaste chain was not sufficient to ensure the plastic was actually recycled.[86]

The impact that these reduced fees previously had on the compostable plastic industry was not quantified.

3.6.1.5 UK

The Resources and Waste Strategy outlines how the British government intend to minimise waste, promote resource efficiency and move towards a circular economy. Key targets of the strategy that may influence the compostable plastic market include:

- Extended Producer Responsibility for packaging by 2023;
- Mandatory weekly separate food waste collections; and
- Beverage Deposit Return Scheme by 2023 (subject to consultation).

An Extended Producer Responsibility (EPR) scheme may result in increases in cost for producers, however there are also opportunities for money from these schemes to be put towards the bio-economy. It is unknown at this stage what form the EPR schemes will be in, and whether they will include compostable plastic.

Mandatory weekly food waste collections will likely make the labelling of compostable plastic simpler. It is not yet clear on whether the treatment methods will be standardised, but this could, in theory, make the treatment of compostable plastic consistent within the UK, and thus a consistent message could be used on labelling making it easier for consumers to understand.

There are currently consultations ongoing, at various stages for each of the four nations, regarding the implementation of a Deposit Return Scheme (DRS) in the UK. It is unclear at this stage how this will affect the biodegradable or compostable plastics market. It will be important for any legislation to clearly define how compostable plastics fall into these schemes, to avoid contamination of mechanical recycling streams.

The UK Plastics Pact (UKPP) is a voluntary commitment from businesses across the plastic value chain aiming to tackle plastic waste. One of the targets of the UKPP is for 100% of plastic packaging within the UK to be reusable, recyclable or compostable by 2025 – five years earlier than the European target. If this target is reached, it is possible that the UK compostable packaging market could see a significant boost until 2025, however then growth is likely to level off as the full market potential is reached.

[86] *Afvalfonds verpakkingen*, accessed 25 June 2019, https://afvalfondsverpakkingen.nl/en/

3.7 Labelling and Communication Assessment

Labelling of compostable and biodegradable products on the market can generally be very confusing to consumers. One common example of bad practice is when a product is described as '100% compostable' – with no explanation of what this means, or guidance on which waste stream is appropriate. It is also often used when a product has not been certified to be home compostable. This can be very misleading, and the layperson could even think that this means the item can be littered and degrade in a short timeframe (this is discussed further in Section 4.4).

It is important to understand the extent to which bad labelling is used on the market, and to look at how the disposal of these products could be communicated more effectively. Eunomia have carried out an analysis on the labelling of products across Europe, and the methodology and results are described in this section.

3.7.1 Methodology

The key challenge in the assessment was to achieve a representative sample. Initially biodegradable or compostable packaging and products was gathered by the project team from the market within Europe. Stakeholders with a cross section of existing views with regard to compostable plastics from across the European market were also asked to send images of products from their own countries. Examples from the UK, Italy, Germany and France were found.

For further details on the representativeness of the sample, see Appendix A.2.0.

3.7.2 Results

The results from the assessment are shown in Table 6 where the majority of the product labels assessed have certifications, however they often do not distinguish clearly between home and industrial composting. The majority of labels also do not clearly state which waste stream the product should go in. Potentially the most problematic category is items which claim to be biodegradable but without specifying the environment which it degrades in, as with no further information, this is the category which consumers may consider acceptable to litter.

Table 6: Clarity of labelling assessment results

	Yes	No
Does the product clearly state that it is biodegradable/compostable?	31	3
Does the product state compliance with EN 13432?	30	4
Does the product display a certification?	25	9

If claimed to be compostable, does the product clearly distinguish between home and industrial composting?	11	23
If stated to be 'biodegradable', does the product clearly define the environments in which it biodegrades in?	1	18
Does the product clearly state which waste stream it should go in?	13	21

Some examples of bad practice that encourage irresponsible behaviour were also present, for example packaging foam chips and carrier bags that claimed to be able to dissolve in water – shown in Figure 12—whilst made from PVA and thus would dissolve, the suggestion that this is a viable disposal method is questionable. There were also several examples of mistranslated messaging, for example a plastic film which was said should be disposed of in own garden compost, otherwise disposed of as 'standard foil' – a mistranslation from German to English – see Figure 13—but suggesting the material could be recycled with conventional plastics. Figure 14 shows a bottle label from Italy – one of the few ridged packaging examples. It is described as both compostable and biodegradable and whilst it instructs that it should be placed with biowaste, the graphics heavily imply that biodegradation in soil or in the open environment is also possible. It does, however include the Italian Composting and Biogas Association (CIC) logo for local compliance with EN 13432 although it is displayed somewhat less prominently on the reverse of the product.

Figure 12: An example of bad labelling practice – unclear message on where a consumer should dispose a product

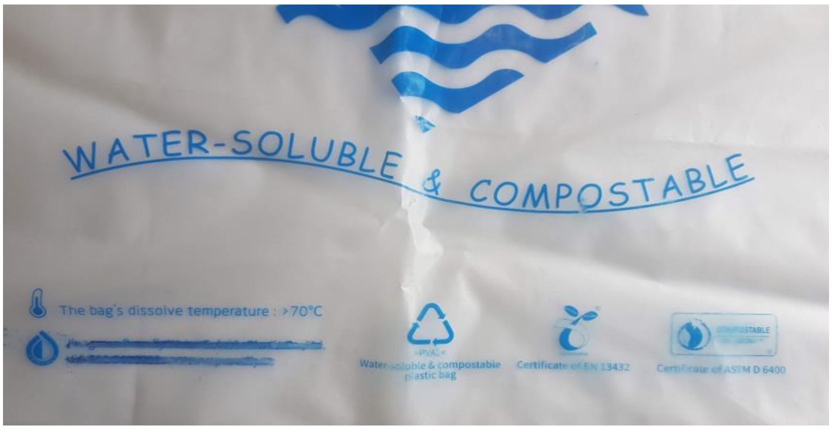

Figure 13: An example of bad labelling practice – mistranslation from German to English causing confusion

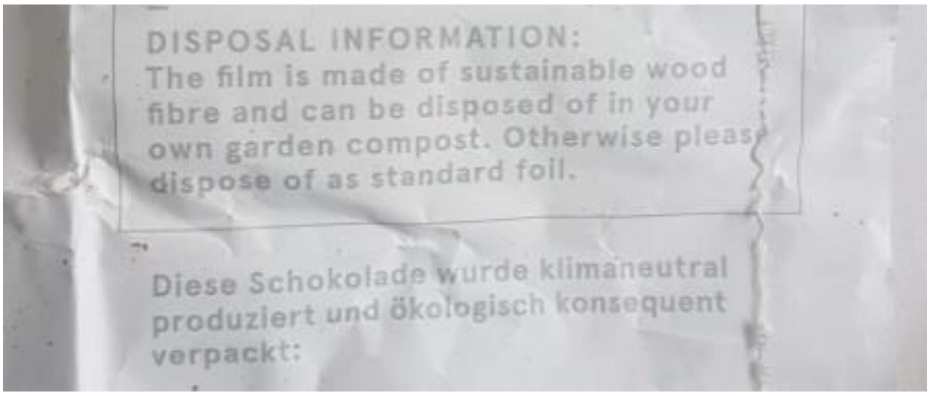

Figure 14: Italian Compostable Plastic Bottle Label

Figure 15 shows an example of what may be considered better practice considering the current availability of appropriate disposal options for these materials. It suggests specific waste streams and where not to dispose of it and displays certification logos. However, it is still vague in language by being non-specific about 'compost' which could mean either household collected or home composting – the certification is for home composting, but this might be confusing for those who do not have this. This demonstrates how complex the messaging is and the difficulty in conveying this even on a larger item such as this plastic bag. The messaging is also likely to be very region specific which is problematic for products sold across Europe as in the example in Figure 13.

Figure 15: An example of good labelling practice – clear instruction on re-use/disposal and accompanying certifications.

Through discussions with stakeholders it was found that product manufacturers are becoming increasingly aware of the need for clearer messaging on products, however there is not always sufficient space to write clear instruction. Vegware are a key example of a company who are looking to improve their on-pack messaging as they have decided to modify their current messaging which contains the terms ‘completely compostable’ and ‘made from plants, not plastic’. The former statement does not provide any specific instruction to consumers and whilst the latter is an attempt to separate the act of composting from plastics recycling in the mind of the consumer, it is factually incorrect to state that PLA is not a plastic.

In future, their products will now have two statements: ‘packaging made from plants’ and ‘commercially compostable where accepted’. Both of these statements are factually correct and will help to make the disposal options clearer.

Vegware have also introduced a green band on some of their products that is intended to be easily identifiable by consumers and composters alike. This is coupled with training for composters in order to recognise this green band and visually identify that the product is not contamination (only for composters that are willing and capable of processing these materials). Whether this has or will be a successful method of identification—particularly for composters—remains to be seen at this time.

3.8 Key Conclusions

Key Conclusions – The EU Biodegradable Plastics Market
The available data on the amount of biodegradable plastic produced is limited, often conflicting, lacking in detail and outdated. This is a result of the structure of the market which is dominated by a few larger manufactures; if one facility closes then the size of the market can change dramatically in a short space of time. As it is a relatively small market compared with conventional plastics, less research is carried out and thus reporting is not as frequent. Identifying exact quantities of specific products on the market is even more challenging. This is because some applications may account for a few hundred tonnes per year which could easily fluctuate as a result

of small changes such as a feedstock shortage or even a single customer buying more or less product in a particular year. It is clear, however, that the strongest biodegradable plastics market application is flexible packaging, and in particular, the various types of compostable or biodegradable bags.

The key applications have been identified by using data for production and from numbers of certified products to determine a top ten list:

- Carrier bags
- Biowaste bags
- Rigid packaging (food and non-food)
- Other flexible packaging (food and non-food, not incl. carrier or biowaste bags)
- Agricultural films
- Single use trays and plates
- Single use cups
- Single use cutlery
- Bags for loose products (vegetables and other)
- Coffee pads, filters and capsules

Determining the share of the above-mentioned products which are certified compostable vs. the share which aren't, be it for the overall market for biodegradable plastics or for specific applications, has not been possible. All European Bioplastics Members (80% of the market) certify their material, but this does not prevent it begin used in applications that might hinder composting (e.g. using thicker material or using it alongside non-compostable materials)

Carrier bags and biowaste bags combined make up almost 60% of the certified product market by number of certifications in 2019, and 68% of the mass of biodegradable plastics product found on the market in 2015.

The global biodegradable plastics market is currently dominated by three different groups of polymers; polyesters, PLA and starch blends. These polymers hold 27%, 24% and 42% of the market respectively.

The labelling of compostable products often is not clear for the consumer, and sometimes incites irresponsible behaviour such as littering of plastics that do not biodegrade in the open environment. Examples of good and bad practice have been highlighted in this section.

4.0 Impacts of an Increase in the Market for Compostable Consumer Plastic Products and Packaging

Whereas the market assessment in Section 3.0 includes mulch films within its scope the scope of this section is restricted to 'consumer plastic packaging and products'. It also focuses specifically on ***compostable*** plastic products. This is because this is the only type of ***biodegradable*** plastic that in principle has a waste management route and a European standard associated with it.

The overall objective of this section of the report is to develop a better understanding of the role of compostable plastics in the context of circular economy and possible trade-offs associated with making products or packaging biodegradable/compostable rather than reusable or recyclable.

In order to achieve this, the following aspects are discussed in subsequent sections:

- Establishing the nature and quality of compost resulting from the composting of biodegradable/compostable plastics
- Implications of Compostable Plastics in Organic Waste Processing
- Establishing the effect of biodegradable/compostable plastics entering plastics recycling streams
- Analysing the evidence base for the littering risks associated with biodegradable/compostable plastics

4.1 Establishing the Nature and Quality of Compost Resulting from Compostable Plastics

In this section the evidence was analysed to evaluate the nature and quality of the compost resulting from composting biodegradable plastics. This includes analysis of Article 6a (4) of Directive 94/62/EC and the evidence for compostable plastics meeting the criteria for contributing to packaging recycling targets.

4.1.1 Compostable Packaging Contributing to Recycling Targets

Article 6a (4) of the Packaging and Packaging Waste Directive (PPWD) 94/62/EC states that;

> *"For the purposes of calculating whether the targets laid down in points (f) to (i) of Article 6(1) have been attained, the amount of* ***biodegradable packaging waste that enters aerobic or anaerobic treatment may be counted as recycled*** *where that treatment* ***generates compost, digestate, or other output with a similar quantity of recycled content in relation to input, which is to be used as a recycled product, material or substance. Where the output is used on land, Member States may count***

it as recycled only if this use results in benefits to agriculture or ecological improvement.”

In other words, the key requirement to establish whether or not packaging can be counted towards the recycling target is whether or not the output from the aerobic or anaerobic treatment of this packaging “results in benefits to agriculture or ecological improvement” where the output is used on land. It is also clear that this implies that any negative effects from the output being used on land would lead to not fulfilling this criterion.

The extent to which compostable plastics will fulfil this requirement is partially down to the way in which *ecological improvement* is defined. The spirit of Article 6(1) is that compostable plastic provides the same, or at least broadly similar, benefits to agricultural soil as the other composted organic matter. This goes beyond the requirements of the current EN 13432 which states that the compost is *“not negatively affected by the addition of that packaging material or packaging component”* according to plant growth test OECD 208. The implication of this is that conformance with this standard does not necessarily imply that the requirements of Article 6(1) are also met.

The Commission Implementing Decision EU 2019/665 of 17 April 2019 was introduced to ensure a common calculation methodology in the PPWD. Article 6C (1d) states that:

> *“Where biodegradable packaging that is subject to aerobic or anaerobic treatment is included in the recycled amounts for the respective packaging material, the amount of biodegradable packaging in biodegradable waste shall be determined by performing regular composition analyses of the biodegradable waste entering those operations.* ***Biodegradable packaging waste that is removed before, during or after the recycling operation shall not be included in the recycled amounts****.”*

The wording of the article excludes packaging which is rejected through pre-treatment (primary screens, hydropulpers, etc.), and at any other point in the aerobic or anaerobic treatment operation. This means that compostable plastics that are placed on the market cannot be assumed to be counted towards packaging recycling targets even in municipalities that use organic treatment facilities that accept these materials.

4.1.1.1 Evidence on the Nature of the “Compost” From Compostable Plastics and the Potential Related Qualitative Benefits

The scientific evidence surrounding the nature of compostable plastic after the composting process (beyond determining any ecotoxicological effects) is distinctly lacking at present. This is likely to be because the focus has been determining that there are no negative effects (e.g. toxic elements introduced into soil) rather than ensuring positive effects (benefits). It is possible that compostable plastic will improve soil structure and stabilise aggregates, but the yields will be very difficult to quantify, which is also the case for 'normal' types of organic material.[87]

A 2008 study comparing using life cycle assessment (LCA) to compare different event drinks cups by the Austrian Institute of Ecology concluded that *"since PLA material does not contain any plant-available nutrients (structural formula) and does not contribute to the built-up of the soil structure, composting is purely a disposal alternative."*[88]

The assertion that it does not contribute to soil structure is contentious. Indeed, the problem of attempting to quantify the *direct* benefits from the composting of plastics is often problematic within LCA—this is especially true when one must make assumptions as to how much material becomes incorporated into the final compost. Several such studies were analysed by the German Federal Environment Agency[89] which concluded that nutrient benefit was negligible and therefore the main benefit would be from providing soil structure, but suggests that if 90% degradation was to occur then soil-structure building would also be negligible. However, the study also noted that manufactures claim that a real-life degradation rate would be closer to 50% (similar to bio-waste) with the reminder enhancing soil structure (in the form of biomass)—this claim is common place, but it is difficult to find substantive evidence for it other than older chemical testing protocols from the OECD only requiring a 60% pass level for biodegradation (this is discussed further in Section 4.1.1.2).

In 2019 the Norwegian Composting facility SIMAS IKS conducted a study by composting 4.2 tons of PLA cups from a festival.[90] The PLA cup was certified to composting standard EN 13432. The PLA cups were shredded to a size of 0-10 mm and composted in windrow composting for 12 weeks together with garden and food waste, in proportions of 10% PLA, 45% garden waste and 45% food waste. The PLA plastic was not visible in the compost after 12 weeks of composting. The final compost product was analysed in a laboratory and classified as the highest quality. SIMAS concluded that the PLA did not have a negative effect on the compost. However, the study did not observe or look for evidence that the PLA had ecological *improvements* in the compost and studies such as this will find it impossible to do so as there are many interconnected variables that prohibit assigning 'benefit' to one particular input.

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[87] Sander Brun., (2019). Personal communication on ecological improvements to soil from biodegradable plastics.

[88] Christian Pladerer, and et al. (2008) *Comparative Life Cycle Assessment of various Cup Systems for the Selling of Drinks at Events*, Report for Austrian Federal Ministry of Agriculture and Forestry, Environment and Water Management, 2008

[89] Systemadmin_Umwelt (2013) *Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics*, March 2013, https://www.umweltbundesamt.de/publikationen/study-of-environmental-impacts-of-packagings-made

[90] SIMAS IKS - Dagny Karin Ugulsvik Alvik. (2019) Erfaringer med kompostering af PLA. https://www.grontpunkt.no/nyhet/vellykket-kompostering-av-pla-glass/

An ADEME study from 2018[91] introduced compostable plastic bags into a composting process and found that this did not lead to differences in agronomic and sanitary quality or pose any ecotoxicological risk to the environment for compost compared to compost without bags added. It met all of the agronomic criteria of standard NF U 44-051 (the French compost quality standard). Again, there was no evidence of any additional *benefits* compared with compost.

For further evidence of the ecological benefit from compostable plastic we can also look at studies for mulch films—these are often the same or similar types of materials that film packaging is made from. Soil health from the use of any kind of mulch film is a much-debated topic—and has been subject to far more research—which may also aid in the current discussion. A recent meta study summarised the current literature on impacts of biodegradable plastic mulch films on soil biological and biogeochemical processes.[92] The important element to focus on is when the films are incorporated into the soil after their purpose has been fulfilled. The study concluded:

- Mulch films incorporated into the soil are generally considered to be safe
- However, ecotoxicity tests focus on one stage of plant growth i.e. gemination. Other (later) effects are less well understood.
- Mulch films can have some effect on microbial activity with increased microbial abundances, respiration, and enzyme activities.
- Mulch films had no measurable impact on nitrification potential of soils but effects on other nutrients remain unknown.

Taken together this suggests there may be long terms effects, but whether these provide net benefits is unclear. Mulch films are also likely to be applied to land in higher concentrations compared to compostable plastics within compost therefore the magnitude of these effects in the latter situation is even less clear.

Finally, there is also recent evidence[93] to suggest that it is possible to modify the compostable plastic to enhance soil quality through adjusting the C/N ratio of the materials and the number of added nutritional compounds. These sorts of innovations are far from being mainstream as yet, but may demonstrate a potential opportunity to improve overall compost quality, although the practicalities of this are unclear at present.

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[91] Déportes I.Z, Le Ravallec V., Mortas N., Thévenin N., and Machinet G. (2018) *Biodégradabilité En Compostage Des Sacs Plastiques Biodégradables (Norme Nf T 51-800) Et Des Sacs En Papier*, Report for ADEME, September 2018

[92] 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

[93] Moreira, A.A., Mali, S., Yamashita, F., Bilck, A.P., de Paula, M.T., Merci, A., and Oliveira, A.L.M. de (2018) Biodegradable plastic designed to improve the soil quality and microbiological activity, *Polymer Degradation and Stability*, Vol.158, pp.52–63

4.1.1.2 Implications for Interpretation of "Ecological Improvement"

From the qualitative side, the key element to be considered is "ecological improvement" (and the similar one, "benefit to agriculture", mentioned in the Commission Decision 2011/753/EU). This may require, in the future, a unified definition at EU level, given its pivotal role in assessing whether a material may be counted as "recycled". In the absence of such EU-wide definition, the subject may be somewhat informed by considering the agricultural purpose of using compost or digestate, which refers to the nature of composted products, their intended role in fertilisation, and related required properties.

A useful definition for "soil improvers" to frame the intended benefits of using compost, is indicated in the Commission Decision (EU) 2015/2099 for the EU Ecolabel for growing media, soil improvers and mulch states that a soil improver:

> *"…means a material added to soil in situ whose **main function is to maintain or improve its physical and/or chemical and/or biological properties** (...)"*

Similarly, the Fertiliser Regulation (EU) 2019/1009 states that a soil improver:

> *"… shall be an EU fertilising product the function of which is to maintain, improve or protect the physical or chemical properties, the structure or the biological activity of the soil to which it is added."*

Both of these definitions align well and allow for soil improvement to be classified as either physical or chemical. From the agronomic angle, compost is considered a *"soil improver".* Arguably, possible "ecological improvement" related to compostable plastics might not necessarily have to be considered in terms of nutrient capacity, but could be considered in terms of the physical soil improving effects related to organic matter. There is currently no evidence to suggest that compostable plastics contribute any chemical benefit—assumed to include the provision of nutrients. The physical benefit gained from compostable plastic—in the form of converted biomass contributing carbon into the soil— is supported by some evidence (as described previously in Section 4.1.1.1.)

Therefore, the nature of compost/digestate as "soil improvers" could be seen as of relevance in relation to the issue of "ecological improvement" to the extent that it, at least in part, indirectly links to various agronomic benefits such as:

- Improved structure and tilth[94]
- Reduced resistance to ploughing and tilling[95]
- Improved water holding capacity
- Reduced energetic input to the primary sector from all previous effects
- Enhancement of microbial and biochemical activities in soils

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[94] Soil tilth is its physical condition of soil, especially in relation to its suitability for planting or growing a crop

[95] Tilling is the agricultural preparation of soil by mechanical agitation

- Increased availability of various nutrients to plant roots, preventing them from being locked onto mineral particles
- Carbon sequestration in soils

This would in principle call for looking at the question of what compostable plastic might biodegrade into from a more **quantitative angle**. In this context one may note that it is implicit in EN 13432 that around 50% of the compostable plastics is mineralised during the composting process—the rest being biochemically converted and incorporated into the output, i.e. compost. This is because the defining threshold concentrations of heavy metals in EN 13432 are 50% of the limits set in the Ecolabel for soil improvers:

> *"It is assumed that 50 % of the original weight of the packaging or packaging material will remain in compost after biological treatment together with the complete original amount of hazardous substances. The limit values are based on ecological criteria for the award of the Community eco-label to soil improvers…and are set at 50 % of the maximum concentration of those requirements."*

The implication being that if 50% of the material is incorporated into biomass then this effectively doubles the concentration of heavy metals. This has long been considered as a reference 'rule of thumb' average for mineralisation of polymers occurring during composting, but it is difficult to find substantive evidence for it other than older chemical testing protocols from the OECD only requiring a 60% pass level for biodegradation. The OECD guideline for testing of chemicals for ready biodegradability (301) states that: [96]

> *"[Lower thresholds are required] as some of the carbon from the test chemical is incorporated into new cells, the percentage of CO_2 produced is lower than the percentage of carbon being used."*

The specified OECD tests are required to be undertaken within 28 days which is not enough time for the microorganisms to fully metabolise the material and expel CO_2 (and CO_2 is the indicator of biodegradation, not the direct result of it). Later tests such as those specified in EN 13432 have adopted 90% as the threshold as the time has been extended (180 days) to allow full mineralisation to take place—this provided more certainty that the material is *inherently biodegradable*.

However, these tests should not be taken as a reference for the fate of compostable plastics in real life. In this respect, most of research available so far on actual mineralisation of compostable plastics, refers to standard lab conditions as defined in ISO 14855, and expresses degradation as a percentage, relative to the reference material (cellulose)[97]. As stated, this does not allow calculation of actual mineralisation (and the related conversion rates into final outputs) in real composting conditions, i.e. how much

[96] OECD (1992) OECD Guidelines for the Testing of Chemicals - 301 A-F - Ready Biodegradability

[97] See e.g. Narancic et al. (2018) *Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution,* Environ. Sci. Technol. 2018, 52, 10441−10452

of the starting polymer has been turned into CO_2 and H_2O, and how much has been incorporated into the output biomass.

A study setting out to answer this specific question was recently carried out by Zumstein et al. (2018)[98], who tested biodegradable mulch films (PBAT): using Carbon-13 labelled polymers which was incubated for six weeks in soil. This study is directly relevant to compostable plastics as the same microbial process takes place albeit at different temperatures and inoculum.

The study found:

- Between 8% and 13% of Carbon from the investigated biodegradable polymers was turned into CO_2 over the six week test period
- Extensive surface colonisation of films by both fungi and unicellular organisms
- Roughly 6% of Carbon in microbial biomass was made of Carbon-13, taken from the Carbon-13 labelled polymers (unfortunately, embodied Carbon was expressed as a percentage of the microbial Carbon, and not of the starting Carbon in the investigated polymers)

Importantly this study also confirmed that microorganisms do colonise the material; that the secreted enzymes do cause depolymerisation on the surface; and, there is microbial uptake of the resulting low molecular weight compounds.

4.1.2 Key Conclusions

Key Conclusions – Establishing the nature and quality of compost resulting from the composting of biodegradable/compostable plastics
To properly interpret Article 6a (4) of the Packaging and Packaging Waste Directive (PPWD) 94/62/EC it must be established whether or not the output from the aerobic or anaerobic treatment of packaging "results in benefits to agriculture or ecological improvement" where the output is used on land. It is also clear that this implies that any negative effects from the output being used on land would lead to not fulfilling this criterion. Direct evidence of ecological improvement from compostable plastics is sparse and inconclusive. There appears to be consensus around the lack of nutritional benefit and therefore this leads towards investigating more in-depth the potential physical benefits of incorporating carbon directly into the soil as biomass. The definition of 'soil improver' in the Fertiliser Regulation and Ecolabel for Soil Improvers indicates that either physical or chemical functions can be considered in this regard.

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

However, the evidence for the extent to which assimilation of the carbon into the compost takes place is also limited. Only recently has the carbon in the polymer been tracked into biomass, but this is difficult to quantify at this stage.

Further research would be required to have a clearer view of how much organic matter becomes mineralised during actual composting conditions and, conversely, how much gets incorporated in the final compost product. Tracking the carbon through the process is very much in the early stages, but does further the understanding of what is taking place (which was largely assumed until this point).

Until such time as the term 'ecological improvement' is further defined it seems reasonable that this could be considered in terms of a 'soil improver' as defined in the Fertiliser Regulation and Ecolabel for soil improvers. In relation to compostable plastic, before considering its benefits analogous to those of a soil improver, further specific study would be needed to determine the exact nature and quantity of the remaining material that does not degrade into CO_2 and water and whether this behaves broadly in similar ways, from an ecological perspective, as the surrounding compost. At this stage the evidence is too weak to arrive at any form conclusions in this regard.

4.2 Implications of Compostable Plastics in Organic Waste Processing

The following sections explore the types of organic waste infrastructure that exists in Europe and the implications of processing compostable plastics within these systems. There is also a particular focus on the countries of Italy and Germany; the former for the significant market of compostable plastics and the latter for the reverse. Case studies and examples from across Europe are also used to broaden the perspective.

4.2.1 Common Organic Waste Treatment Methods

There are broadly three different kinds of organic waste treatment systems that are commonly used throughout the EU:

- Anaerobic Digestion (AD)
- In Vessel Composters (IVC)
- Open Air Windrow (OAW) or Aerated Static Piles (ASP)

The following sections describe these processes in high level to provide context for the discussion in later sections that looks at some of the issues reported by these types of plants.

4.2.1.1 Anaerobic Digestion (AD)

AD is increasingly considered the preferred method for processing food waste from an environmental perspective. This is because it is an enclosed process that generates methane in the form of biogas which is a high value output and can either offset fossil gas production or be burned to produce electricity on site resulting in an overall net benefit in terms of climate change mitigation.

Food waste, rather than garden waste from household sources, is generally preferred in AD facilities. This is because garden waste has a lot of wood-based (lignin) materials which will not break down in AD quickly or produce much biogas and consequently it is more cost effective to use open air windrow of IVC for most garden waste.

The two main variations of the AD process that are relevant to the present discussion are wet and dry processes. In a 'wet' process there is generally less than 15% dry matter which is pumped around the system rather than layered. The UK, Denmark, and Norway commonly use this process. The process is also often mesophilic (~37 ° C) rather then the higher temperatures in other composting a dry AD processes. Digestate is the primary output by weight; this is a slurry-like substance which can be applied to agricultural land, but has less nutritional benefit than mature compost— it is very high in mineral nitrogen and ammonia with very little carbon content to provide structure to the soil and cannot be applied all year round.

The 'dry' AD process which is has a much lower water content (15-45% dry matter) and will often be more efficient and cheaper to run as the heat required to accelerate the degradation is not wasted on heating water—conversely the set-up costs of dry AD are higher than wet AD.[99] The dry batch systems, which operate at higher levels of dry matter, do not use pumps and pipes—materials are moved through front-end loaders—and they generally have fewer problems with plastic contamination fed into the process, with contaminants removed at the end of the process, during the final refining step.

This is more common in Italy and Austria and generally also includes a secondary composting stage to stabilise the digestate to meet the end of waste status. This can increase the value of the digestate, both in economic and agronomic terms as the balance of nitrogen and carbon is closer to compost and therefore it can be used for a wider array of applications.

The business model for AD often depends heavily on income from biogas generation, particularly in countries where renewable energy subsidies are/were available such as the UK and Germany (reduced significantly in 2014). Under these circumstances the digestate quality is often of lesser importance as the incentive is to maximise biogas production.

According to the European Biogas Association there are 17,432 biogas plants operating in Europe as of 2017 – this includes all types of AD including wastewater sludge as well as landfill gas capture.[100] 10,971 of these are situated in Germany – the vast majority are used to process agricultural waste which is also true for most other EU countries. AD plants designed specifically for household food waste, represent a much smaller proportion of the capacity across Europe and are almost non-existent in Germany

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[99] https://www.biogasworld.com/news/dry-wet-anaerobic-digestion-systems/
[100] https://www.europeanbiogas.eu/wp-content/uploads/2019/05/EBA_Statistical-Report-2018_AbrigedPublic_web.pdf

(although this is beginning to change[101]). This demonstrates that the technologies have not grown up around the requirement to treat food waste and it is often the case that plants (or the underlying technology) have been adapted from taking different feed stocks. These are even less well equipped to deal with plastic contamination which is typically only a problem in food waste.

In Denmark a senior Danish composting sector representative interviewed in the context of this study revealed that one AD site is composed of an anaerobic step with a final aerobic maturation stage; as such, the system had no problem in processing compostable plastics, and support was expressed for the specific use of compostable bags, so as to a) increase captures and b) minimise contamination from conventional plastics. Conversely, other sites processing food waste collected from Copenhagen (and other bordering municipalities) are co-processing this with manure, which requires prior pre-processing that turns food waste into a pulp; the main fate of compostable plastics there, is to end up in final rejects (residual waste going to incineration).

As a consequence, the pre-processing company argues for the use of conventional plastics. The City of Copenhagen keep using and supplying compostable plastics, since it is argued that small fragments that may end up in the pulp that is sent to anaerobic digestion will ultimately biodegrade, which would not be true for conventional plastics.

This indicates that acceptability may vary depending on the operational scheme of the site even within countries.

An aspect of AD that is less well understood (and certainly poorly communicated and managed by EN 13432) is that because the process is anaerobic that not all compostable plastics are suitable. Different polymers are degraded by different microorganisms, and different microbial communities may be available depending on the composition of the waste that is used. A typical wet AD plant operates with a hydraulic retention time[102] (HRT) of 15–30 days, but only certain polymer types are theoretically capable of biodegrading within that timeframe where materials such as PCL, PLA and PVA take longer.[103] This is problematic as all of these materials are known to biodegrade in other composting processes and are often certified as such.

A 2019 study by French waste management company, Suez, tried to determine how PBS, PBAT and PLA bags actually perform in mesophilic AD plants by simulating at a lab scale and measuring methane production.[104] It found that they had weak anaerobic biodegradability with limited or no methane production after 21 days of digestion. This is in comparison with paper bags which showed "satisfactory biodegradation." The authors

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[101] http://adbioresources.org/news/running-an-ad-plant-lessons-from-germany

[102] A measure of the average length of time that a compound remains in the bioreactor

[103] Bátori, V., Åkesson, D., Zamani, A., Taherzadeh, M.J., and Sárvári Horváth, I. (2018) Anaerobic degradation of bioplastics: A review, *Waste Management*, Vol.80, pp.406–413

[104] Laure Constans, Maxime Rouez, Marion Lespiell, and Justine Auclair (2019) *Plastiques compostables : biodégradabilité anaérobie et contribution à la production de méthane*, Report for Suez, December 2019

also comment that the persistence of the physical integrity could pose mechanical problems with the AD process, and indeed this is a known problem for some operators.

4.2.1.2 In Vessel Composters (IVC)

In vessel composting is used throughout the EU for treating food and/or garden waste. There are several types and variations of the process as well as several stages, but it is in essence, primarily a controlled composting process exposed to oxygen rather than a digestion process in the absence of oxygen.

IVC operators still have similar challenges with regard to plastic contamination as AD operators, but there are no pipes or pumps to block and disrupt the process. However, some sites still have primary screens that may send plastics and compostable plastics into rejects. This is a common practice in Germany where conventional plastic bags, which are often used by households to deliver biowaste, are removed.

UK waste contractor Biffa[105] state that they do not accept compostable plastics in food waste streams as their processing sites as it will merely been screened out. Biffa have run trials with PLA items in IVC sites but this showed that the products weren't biodegrading fully after being shredded coarsely and integrated into the biowaste. A smaller shred size improves this, but there is a real concern as to how to manage the potential cross-contamination in this stream from conventional plastics which would also be shredded and therefore impossible to remove later – at the moment there are no checks between collecting it, fine shredding it and then going into the compost mix. Larger fragments take longer to compost which makes it less economical but are easier to remove if not fully composted. Screened material generally goes to energy from waste (EfW).

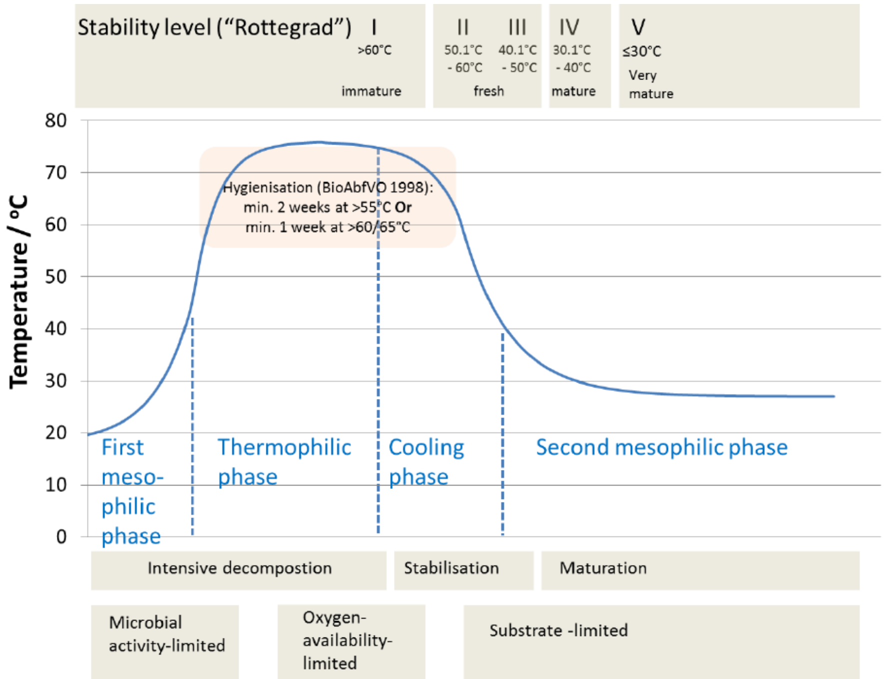
One of the most important aspects to understand is that the compost output will vary dramatically dependently upon how long it is processed for. There are a number of, primarily economic and regulatory, drivers for the reasons why a facility may choose to produce compost that has not yet fully matured.

Germany use a voluntary, but well established Rottegrad classification system, developed by the Bundesgütegemeinschaft Kompost[106] (BGK) which grades compost maturity level for certain applications (and certifies to quality standard RAL-GZ 251 of which 70% of compost in Germany carries the marque[107]). The two main examples are mature compost (graded IV-V) and fresh compost (graded II-III). The maturity level can be determined by measuring the self-sustaining temperature that the compost exhibits or the oxygen consumption – either test indicates the activity level in the compost. mature compost is generally used for higher value (horticultural) applications, such as gardening, landscaping, greenhouses and tree nurseries, whereas fresh compost is

[105] Teleconference call to Eunomia in Spring 2019
[106] Federal Quality Compost Association
[107] https://www.kompost.de/uploads/media/Compost_Course_gesamt_01.pdf

typically applied directly to agricultural land — the latter can be composted for as little as 6-8 weeks. Figure 16 shows industrial composting process over time where the temperature increases with biological activity and decreases as the carbon is metabolised. The Rottegrad system is shown for reference which demonstrates that there is still a great deal of microbial activity taking place in 'fresh' compost, which makes it only suitable for a limited set of applications.

Figure 16: The Industrial Composting Process in the Context of the German "Rottegrad" Maturity System



Source: WRAP (2016)

The implications for putting compost on agricultural land that has not fully matured are that the land should ideally not be planted (especially with more sensitive crops) until the maturation has finished —for marketing purposes in Germany this results in a lower cost product. The agronomic benefits—or lack thereof—of fresh compost is the subject of much debate in Germany and providing conclusions in this regard is out of scope of the current study. However, a literature review of the issues around compost stability by WRAP from the UK (but looking at literature across Europe especially from Germany where much of the research has been conducted) concluded that *"Agricultural and field* *horticultural trials have not shown significant agronomic problems when less mature composts have been used."*[108]

Nevertheless, these particular practices are unlikely to be compatible with the conditions that are specified in EN 13432 (see Section 5.0 for the discussion on this aspect) and appear to be one of the key barriers to compostable plastics in Germany.

Conversely, Italy has a general minimum requirement that compost should mature for at least 90 days (up to twice as long as German fresh compost) as well as fulfilling other minimum quality criteria. Digestate is also still considered a waste (whereas in other countries it can be used directly on land , albeit in Germany land spreading is considered as an R10 operation, i.e. still dealing with a waste) and requires post-composting in order to achieve the status of a product which can be sold — this is in line with assumptions on which requirements appear to be based in EN 13432 for treatment in aerobic conditions.

A study in the Netherlands[109] put various compostable plastic items (plant pots, bags, teabags and coffee pods all certified to EN 13432) through an industrial composting process and analysed the level of disintegration that could be observed. The composting cycle of 11 days (on the lower end of practice in the Netherlands) was not sufficient to completely disintegrate most of the compostable products (orange peel and banana skin reference materials also did not fully disintegrate, however). Facilities that recirculate unfragmented plastic through the process would not find this problematic although this only happens down to a size of 10 mm. Further degradation is likely to take place during a subsequent maturation phase, but the compost is often utilised in the Netherlands without this step. The authors focus on 'visible 'contamination and note that brightly coloured coffee pods showed up more often – no comment was given on actual contamination and whether it would then subsequently be applied to land. The main focus was on whether the compostable plastic would result in rejection of the compost due to visual checks. Plants that have any pre-treatment or separation stage and the beginning will remove much of the compostable plastic for residual treatment – this is common in the Netherlands. In the context of the present study this further demonstrates that considerable variation exists in both products and composting processes to not fully guarantee full biodegradation of compostable plastics in the Netherlands, although it appears to be possible for processes to be optimised to achieve this.

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108 WRAP (2016) *Literature review: Compost stability – impact and assessment*, July 2016

109 Maarten van der Zee, and Karin Molenveld (2020) *The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility*, Report for Dutch Ministry of Economic Affairs and Climate Policy, February 2020

4.2.1.3 Open Air Windrow (OAW) and Aerated Static Piles (ASP)

The open air windrow (OAW) is the most basic form of composting facility and very similar to home composting in that the organic material is piled up, usually outside, and left to compost naturally. The windrows are turned regularly to aerate and redistribute the material (while static piles are usually not turned) and some more sophisticated operations use air blown through pipes embedded in the ground underneath. Some facilities are under roofs or fully enclosed which blurs the line between this an IVC. Higher—thermophilic—temperatures can be achieved due to the overall mass of the organic matter generating and maintaining heat throughout the process. These higher temperatures set the process apart from home composting and the biodegradation process as a whole is very similar to IVC as they both take place in the presence of oxygen.

A 2018 study carrier out by ADME in France[110] found that composting time needs to be extended in the presence of compostable plastics (in this instance, biowaste bags). At least 6 months of composting in an aerated static pile was required to stop observing bag fragments plastics in the screened compost. It is unclear whether the lack of visible fragments resulted in full biodegradation (although the study found that microbes were colonising the material), but this timescale fits with the 6 month requirement in EN 13432. Any similar process that does not adopt at least this timescale is therefore likely to find visible fragments in the compost.

4.2.2 Effects of Contamination of Biowaste and Compost Quality

One may also be concerned about possible detrimental effects of compostable plastics on the *quality* of collected biowaste, which may in turn, negatively affect compost quality.

A higher level of impurities in collected biowaste may be directly detrimental to the quality of the composted output (e.g. a higher visual contamination, since the final refining steps are never 100% effective) and/or affect composting operations and costs, requiring additional separation steps and increasing the percentage of rejects.

From the European Compost Network (ECN) position paper[111], and based on the state of discussions at the ECN Working Group on bioplastics (which includes representatives of

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[110] Déportes I.Z, Le Ravallec V., Mortas N., Thévenin N., and Machinet G. (2018) *Biodégradabilité En Compostage Des Sacs Plastiques Biodégradables (Norme Nf T 51-800) Et Des Sacs En Papier*, Report for ADEME, September 2018

[111] European Compost Network (2019) *ECN Position Paper on the Acceptance of Compostable Plastics*, October 2019

most EU Countries), according to Ricci[112], by and large, there seems to be a certain agreement in the composting sector, around the following principles:

- Compostable bags may be considered as a tool for separate collection (although this may have variations in different countries, as already identified)
- The same may be valid, to some extent, for specific items in "closed loop" systems as e.g. in event management (e.g. when reusable tableware is not suitable for whatever reason) or disaster relief operations (where reusable tableware may be inherently problematic)
- Use of compostable plastics as a direct replacement for plastic items (including packaging), may create various degrees of confusion with conventional plastics, since it may increase the degree of confusion amongst the end users, resulting in cross-contamination of conventional plastics (going to mechanical recycling) and compostable plastics (going to compost sites).

Concerns about quality may arise from any of the following, or their combined effect:

- Specific pollution (e.g. heavy metals) potentially brought into the system by compostable plastics.
- Incomplete biodegradation (or incomplete conversion into compost).

These points are addressed in the following sub-sections.

4.2.2.1 Pollution and Physical Contaminants

The recently published (June 2019) EU fertilisers regulation[113], provides a common definition of compost standards in the mid-term (the Regulation will entry into force by July 2022). In the meantime, national standards are applicable. The last overview on EU standards for compost (and digestate) was performed by the JRC in 2013 (published in 2014)[114]. As with previous surveys, the JRC report confirms there are two main areas in which standards are defined:

- pollutants (mostly heavy metals)
- physical contaminants ("impurities": glass, plastics etc.)

The former is covered by EN 13432, in that it sets a threshold for heavy metals in compostable plastics at 50% of maximum allowable concentrations defined by the EU Ecolabel for soil improvers (considered as a possible reference for "high quality soil improvers").

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[112] Interviews with Marco Ricci, Chair of Working Group on bioplastics at ECN.

[113] Regulation 2019/1009, laying down rules on the making available on the market of EU fertilising products, published OJ of the EU, 25 June 2019

[114] JRC, End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals, Luxembourg, 2014

On the issue of impurities from physical contaminants, the reported maximum allowable concentrations according to the JRC are shown in in Appendix A.3.0 (along with recent values adopted in Denmark, not reported by the JRC). This shows that most standards limit values for plastics either separately (typically between 0.15% and 0.3%) or as part of an overall limit on "physical contaminants" (typically around 0.5%, but with Spain requiring a maximum of 3%). Impurities are defined by their size, with anything below 2mm being acceptable for all countries except France which allows impurities up to 5mm.

Similar provisions for setting maximum allowable percentages of physical contaminants are included in the EU Regulation on Fertilisers, which, when describing requirements for compost and digestate to qualify as a CE marked Fertiliser (therefore allowing for cross border movement), requires a maximum of 0.3% impurity from plastics >2mm and from 2026 this will be reduced to 0.25%. By 2029 this limit value will be further assessed as the impacts of separate collection of biowaste become clearer.

Importantly, none of the Member State or EU level Regulations take into account the impacts of microplastics on the terrestrial environment or seeks to reduce these. Currently the size limit is 2mm which is larger than the definition of microplastics (typically <1mm). This is potentially problematic for all types of plastic, but in the context of this report, incomplete biodegradation or fragmentation may create plastic particles that fall below these limit values and are therefore not targeted for removal. Under the Fertiliser Regulation it is clear that such contaminated fertiliser could by exported and used in other EU countries. The risk of this is not entirely clear for fertiliser from digestate as the Regulation stipulates several process types that are suitable (including an *option* of secondary maturation), but these are all focused on eliminating pathogens in the digestate and not on successful biodegradation of plastics. Further testing under each one of the processes identified in the regulation would be required to verify this.

Removing impurities is a continued problem for composters especially as local quality protocols become stricter. A comprehensive joint research programme[115] was carried out by the Italian composting network (CIC) together with the national Packaging and Plastic Packaging Recovery Organisations CONAI and COPREPLA; the programme was aimed at monitoring a) fate of plastics and compostable plastics in the composting sector, and b) potential issues related to cross-contamination. In that context, CIC reported the so-called "dragging effect". This is the issue of the increased rejects from the organic recycling process (including organics unintentionally discarded) caused by the need to screen out conventional plastics.

This "dragging factor" (calculated as the proportion *total mass of rejects : amount of plastics in impurities*) is on the average 400% (with range values from 50 to 1,400 %); **in other words, each unit weight of plastic that is screened out, results in a four-fold**

[115] Centemero, M.: Accordo di Programma tra Assobioplastiche, CIC, CONAI, COREPLA, Resoconnto sintetico delle attività di monitoraggio, Proc. of the dedicated event, Milano, 2017

increase in the amount of overall rejects. This has negative effects on mass balances and total efficacy of the composting strategy as a recovery route for organics. This also impinges to some extent on the economics of composting, and is one of the contributing factors as to why the Italian composting sector has embraced the use of compostable plastics along with the phasing out of primary screens.

4.2.2.2 Incomplete Biodegradation/Disintegration

Concerning incomplete biodegradation, which will also be considered further on the issue was investigated in a Report by a specific Working Group established by the Italian Packaging Recovery Organisation CONAI[116]. The report included results of composting trials at various blending ratios between separately collected organics and compostable plastics added on purpose (PLA and Mater-Bi); blending percentages were ranging from 1 to 5%, and included both films and rigid plastics such as bottles, trays, cups and tableware. All tests showed above 90% disintegration in 12 weeks, thereby meeting the requirements of the disintegrability and compostability test stipulated by EN 13432.

With regard to a potential increase of rejects, and incomplete biodegradation, SUEZ (2018)[117] based on internal studies, came to the following position:

> *"In current industrial methanisation conditions, compostable (...) plastics are sorted out before entry into anaerobic digestion facilities. During our study, we confirmed that **compostable plastics hardly degrade during tests in anaerobic controlled conditions.** The risk for microplastics in the soil and in digesters is therefore real."*

A similar position was expressed by a coalition of sectoral German waste management associations[118], whose position reads:

> *"Biodegradable plastics may seriously adversely affect the quality of the end products (compost and digestate), as it **cannot be guaranteed that they will disintegrate and biodegrade adequately during the course of the different biological treatment** processes; this is particularly important given current biowaste processing timescales. Furthermore, it cannot be guaranteed that at the end of a biowaste treatment process, particles of biodegradable plastics greater than 1 mm in size (which will be classed as physical contaminants/impurities) will not be present"*

The statement was also categoric that outside of the use of bags[119], no other plastic products should be labelled as compostable. The primary concern is aimed at the lack of

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[116] CONAI, WG Biodegradable Packaging Recovery Project, *Final Report,* 2012

[117] SUEZ (2019)*SUEZ recommendations concerning Bio-sourced and Compostable Plastics*

[118] German Waste and Biowaste Associations (ANSK, ASA, BDE, BGK, BVSE, DGAW, Fachverband Biogas, VHE, VKU, 2019) *Position Statement on the disposal of biodegradable plastics through bio-waste treatment*

[119] Bags were considered out of scope for the position statement under the premise that they are acceptable if approved by the 'relevant local public authorities for waste management and in close co-operation with bio-waste treatment companies."

adequate biodegradation in AD plants under current processing times. The same issues have been highlighted in several countries—including the UK, Denmark, and Norway that use AD extensively to process food waste, but do not operate a secondary composting stage (unlike most Italian plants) due to wet processing.

4.2.3 Cost implications of biodegradable/compostable plastics in organic waste processing

The previously mentioned recent Commission Implementing Decision EU 2019/665 of 17 April 2019 sheds additional light on this in Article 6C (1d):

> *"Where biodegradable packaging that is subject to aerobic or anaerobic treatment is included in the recycled amounts for the respective packaging material, the amount of biodegradable packaging in biodegradable waste shall be determined by* ***performing regular composition analyses of the biodegradable waste entering*** *those operations. Biodegradable packaging waste that is removed before, during or after the recycling operation shall not be included in the recycled amounts."*

The wording of Article 6C (1d) in the Commission Implementing Decision EU 2019/665 appears to state that the recycling rate of compostable packaging will be determined by regular sampling of composting operations, so as to determine amounts that get discarded into the rejects, and amounts that gets converted into compost through the composting process; this is something that does not take place in respect to compostable plastics at most facilities at present and therefore will incur additional cost. Currently there is no way for composting facilities to regain those costs until a form of EPR is introduced. There is also the additional issue of determining what is and is not packaging especially if the majority of compostable plastics are flexible films without particularly distinguishing characteristics.

This is problematic for composters, who may be required to test for the presence of compostable plastics. Arguably this requirement may induce composters to refuse to accept any organic waste that is likely to contain these materials in order to reduce these costs. This may have a considerable impact on the more widespread use of compostable plastics if this takes place.

A potential approach to work around the issue was adopted through the research programme[120] carried out jointly by the Italian Composting Association CIC and the Plastic Packaging Recovery Organisation COREPLA, which surveyed, *inter alia*, the presence of compostable packaging going to composting and anaerobic digestion sites, so as to ascertain the contribution of organic recycling to general recycling rates for packaging.

[120] M. Centemero, Accordo di programma tra Assobioplastiche, CIC, CONAI, Corepla, Resoconto sintetico delle attività di Monitoraggio, 2017

The survey was based on sampling at 27 sites (15 composting sites and 12 combined anaerobic digestion + composting sites), representing a total processing capacity of some 2 Mt/year (out of a national total of 6 Mt).It was set up to determine an *average* percentage of compostable plastics, and compostable packaging, in the input material and in the rejects. Once multiplied with the total processed tonnage, this makes it possible to calculate the contribution of organic recycling to total packaging recycling rates. Such an approach would transfer the monitoring system from each given site, to the system as a whole, with the organisational and economic burden born by the producer responsibility organisations (PROs). Nevertheless, as the EU calculation rules are relatively new, there are no standardised process for tackling this issue at present.

4.2.4 Case Study: Effects of Compostable Bags on Separate Collection of Biowaste

To date, one of the main uses of compostable plastics in the EU has been for biowaste bags which are used to make collection of food waste more user friendly (when used to line a kitchen caddy), thereby maximising participation and capture. Biowaste bags are also commonly made from conventional plastic (either formally, or by reusing carrier bags) and paper (again, either formally, or with the householder lining the caddy with newspaper, for example).

Compostable bags for collection of source separated food waste are largely used in Norway, Italy, Spain (Catalonia, Basque Country), the UK and Ireland. The compostable bag is designed to enter an industrial composting facility together with the food waste. However not all EU countries have composting facilities suitable for food waste. Food waste is also treated in anaerobic digestion (AD) plants, for which the compostable bags are not intended unless a secondary composting phase is used.

This is also the only compostable plastic product that the European Compost Network (ECN) support more widespread use of in a recent position statement[121] (assuming that the local infrastructure is capable of accepting these materials). The ECN class them as 'Type 1 - Tools that are functional to ease the users in the separate collection of bio-waste', although much of the evidence cited in the position statement comes from Italy where compostable biowaste bags have gained a high level of acceptance already.

4.2.4.1 Positive Examples of Comparing Compostable with Conventional Plastic Biowaste Bags for Food Waste Collection

When determining whether compostable bags are beneficial it is important to compare these with other materials. There are many studies that have investigated various ways in which householder participation in biowaste collection can be maximised, but fewer have isolated the effects specifically to material. However, there are indications that compostable bags reduce contamination and increase participation. The following

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[121] European Compost Network (2019) *ECN Position Paper on the Acceptance of Compostable Plastics*, October 2019

examples of this are from two countries that generally have a low acceptance of compostable plastic and therefore the results may be more instructive.

Research for the City of Copenhagen[122] and a test study for the Danish Environmental Protection Agency[123] comparing compostable and fossil-based plastic bags found that the compostable plastic bags have the following benefits:

- The food waste collected with a compostable bag is less contaminated with other materials;
- the compostable bag is likely to biodegrade over time if it is not properly sorted out and ends up in the digestate/the field;
- compostable bags provide a good signal to citizens to sort the food waste correctly; and,
- citizens perceive the compostable bag as more environmentally friendly.

The last two points are difficult to untangle and are primarily related to consumer perception. The studies were initialled by Copenhagen City Council after it emerged that the compostable bags that were being supplied were made from fossil-based material. The Council and the public had a general perception that; compostable = bio-based = 'environmentally friendly'. As previously discussed in this report, these three aspects are not linked at all. The city is continuing to supply the bags, which may be requested through an online Municipal delivery service, but now required to include a minimum 50% bio-based content.[124] This demonstrates that perceptions appear to be just as important in driving behaviour as the actual performance of the material in practice.

A recent study was performed by the Witzenhausen Institut in Germany where 13 cities and municipalities were examined for the factors which affect compost quality from household organic waste. One of the main conclusions was that:[125]

> *"The widespread fear that the admission of biodegradable bags leads to an increase in impurities could not be verified during the analyses. On the contrary, the admission of biodegradable bags resulted in fewer impurities in biowaste."* (translated from German)

The difference between municipalities that discourage or ban composable bags and those that recommend them is around a 30% decrease in impurities for the later. However, as this was a survey of existing practice it is not entirely certain that other factors do not contribute to this difference.

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[122] COWI. (2018). Opsamling af viden om indsamlingsposer til bioaffald. City of Copenhagen.
[123] COWI. (2017). Posekvalitetens og materialets betydning for indholdet af fysiske urenheder i biopulp. Financed by Danish EPA.

[125] M. KERN, H.-J. SIEPENKOTHEN, T. TURK (2018): Erfassung von haushaltsstämmigen Bioabfällen und Qualität des Bioguts - Auswertung von Biogut-Sortieranalysen. In: Müll und Abfall 10/2018, S. 526-531

Overall from the above examples evidence suggests that using compostable plastic collection bags compared fossil-based plastic bags can potentially increase the amounts collected—through increased participation, albeit potentially due to consumer misunderstanding of the environmental benefits of the material itself—and decrease the contamination. No evidence or examples were found for the reverse.

4.2.4.2 Concerns and Issues with the Use of Compostable Bags for Food Waste Collection

A large variability may be detected, across different EU Member States, in the way the composting sector accepts or considers the use of compostable biowaste bags.

The German BGK (the National Composting and Quality Assurance Network) reports low acceptance of compostable plastics by operators. Delivery of compostable packaging or other materials in a bio-waste bin is not permitted with the exception of bags for collection of kitchen waste (in a few Municipalities), and it is generally not desired by the plant operators. A survey by BGK from 2018, reports that 88.6% of respondents reject the use of compostable plastic bags, while site managers prefer paper (bags or newspaper) for collection of biowaste.[126] The reasons for this typically refer to;

- the presence of primary screens, which is widespread at German compost sites in order to remove impurities (including conventional plastic shopping bags which are often used by households to contain biowaste); and,
- the duration of composting is shorter than required by EN 13432 to ensure biodegradability and compostability (as described in Section 4.2.1)

As a consequence of the low acceptance of compostable bags by German compost sites, many Municipalities in Germany do not require, and in some cases prohibit, the use of compostable bags for separate collection. In data reported by DUH[127], in a survey on some 400 Municipalities in 2016, 74% prohibited the use of compostable bags, and only 12% were considering them (the remaining, i.e. 14% of the Municipalities, were not running schemes for separation of food waste).

In the UK, while biowaste bags are used in many local authority areas, they are not mandated and since the UK uses wet AD process for food waste (as opposed to dry AD in Italy for example), all bags have to be removed as far as possible in the pre-digestion maceration and screening. Given that some shredded bag material is still likely to pass through to the digester, it is often still preferable for this material to be made from compostable plastic rather than conventional plastic, however wet AD plants in the UK still report that any plastic material, compostable or otherwise, is a problem as it can block pumps, pipes and valves in their wet systems and accumulate.

[126] European Compost Network (ECN), Survey on acceptance of compostable plastics in various Countries, personal communication, 2019

[127] Deutsche Umwelthilfe (DUH), *Presentation at the stakeholders' workshop*, Brussels, 2019

Similarly, in Denmark the food waste is mainly treated in wet mesophilic[128] AD plants where the collection bags are sorted out in the pre-treatment. In recent years many municipalities have chosen to collect food waste with a fossil-based plastic bag. The pre-treatment plants report that the compostable plastic bags are more prone to causing problems with blocking pumps, sticking to screws and other equipment as the compostable bag are more easily stretched (lower tensile strength). Moreover, the pre-treatment plants report that the compostable bags, in some cases, have started disintegrate into smaller pieces before reaching the pre-treatment plant making it harder to sort out and thereby increasing the potential of plastic contamination in the final digestate. Yet another problem pointed out by pre-treatment plants is that the food waste sticks to the compostable bag and when the bag is sorted out a larger part of the food waste is also sorted out[129].

These experiences from compostable plastic bags for food waste collection are specific to this application, but some points can be taken away for compostable plastics in general:

- When it comes to compostable bags the positive effects primarily relate to the purpose of facilitating increased or improved collection of food waste and a reduction in contamination, and there is reasonable evidence to suggest this is the case.
- Despite this there is still no universal acceptance. Other products which cannot demonstrate such benefits to composters will have an even harder time becoming accepted.
- The difference in collection method, processing and the approach to removal of conventional plastic contamination all affect acceptance. These vary considerably within the EU and even within Member States.

4.2.5 Key Conclusions

Key Conclusions – Implications of Compostable Plastics in Organic Waste Processing
With regard to the extent to which the use of compostable plastics harms compost quality both; • **Directly by bringing pollutants in the compost mix:** this is addressed by EN 13432, but there is suggestion that the current ecotoxicity criteria are not strong enough to guarantee no negative effects, and;

[128] Mesophilic systems operate at 25-45°C and thermophilic systems operate at 50-60°C or above. Thermophilic systems can process organic waste faster and produce more biogas production and there is greater pathogen removal. However, the capital costs of thermophilic systems are higher as more energy is required to heat and management is more complex.
[129] COWI. (2018). Opsamling af viden om indsamlingsposer til bioaffald. Københavns Kommune.

- **Indirectly by increasing contamination from conventional plastics.** This does not seem to be evident in surveys that exist on this topic, however such surveys at present only refer to use of compostable biowaste bags, which is the most widespread application of compostable plastics. Questions may arise, on the possible effect of a larger application of compostable plastics for e.g. packaging. More research may be needed to foresee (or detect) the effect of a larger use of compostable plastics in the packaging sector.

With regard to **incomplete biodegradation**, several stakeholder report this taking place in AD and composting plants. The primary concern is aimed at the lack of adequate biodegradation in AD plants under current processing times. The same issues have been highlighted in several countries—including the UK, Denmark, and Norway that use AD extensively to process food waste, but do not operate a secondary composting stage (unlike most Italian plants) due to wet processing. This is also an issue for German composters who use a shorter processing time to produce 'fresh compost.'

Importantly, none of the Member State or EU level Regulations take into account the impacts of microplastics on the terrestrial environment or seeks to reduce these. Currently the size limit is 2mm which is larger than the definition of microplastics (typically <1mm). This is potentially problematic for all types of plastic, but in the context of this report, incomplete biodegradation or fragmentation may create plastic particles that fall below these limit values and are therefore not targeted for removal. As compostable plastics are not routinely tested for biodegradation in soil conditions, the implications of this are unclear.

From existing surveys of composters and direct interviews with several operators the following observations can be made:

- Concerns are expressed by some national compost networks about use of compostable plastics, particularly in Germany. Concerns refer to the increase of rejects (which is not, strictly speaking, related to compost quality) or to not fully biodegraded compostable plastics in the end product. Other national networks in situations with a widespread use of compostable plastics and a long track record, such as in Italy, did not report such problems, and show supportive to the use of compostable plastics. The disparity between these two countries at either end of the acceptance spectrum for compostable plastics can be attributed, in part, to the different composting process that take place; Germany with its acceptance of a short processing time (6-8 weeks) to produce 'fresh compost', compared with Italy and its mandatory 12 week process and secondary composting stage after aerobic digestion.
- At present, the operational design at locally available compost sites is very influential on the acceptability of compostable plastics.
- In particular; compost sites with primary screens divert compostable plastics (together with non-compostable ones) towards rejects. When considering promotion of compostable plastics, primary screens should be concurrently phased out, as is typical in those areas where the use of compostable biowaste

bags is most widespread. Screening of non-compostable plastics can take place at the end of the process.

- Most AD (anaerobic digestion) systems find it difficult to handle compostable plastics (and meet subsequent quality standards for physical contaminants), if not followed by a final maturation stage by means of composting—some countries use a 'wet' AD process which cannot be followed by a composting stage.

Overall from the examples identified in this study, evidence suggests that using compostable plastic collection bags compared to conventional plastic bags can potentially increase the amount of biowaste collected—through increased participation, albeit potentially due to consumer misunderstanding of the environmental benefits of the material itself—and decrease the contamination. No evidence or examples were found for the reverse.

4.3 Establishing the Effect of Biodegradable/Compostable Plastics Entering Plastics Recycling Streams

In the view of an increased diffusion of compostable plastics on EU markets, one should consider possible cross-implications with the recycling of ordinary plastics. In this respect, concerns have been raised, related to increased presence of compostable plastics in plastics collected for recycling.

From this standpoint, one must address concerns on potential negative effects of increased biodegradable/compostable plastics entering plastic recycling, which refer to any or all of the following:

- Higher loss rates of recyclable plastics due to contamination with compostable plastic;
- Lower efficiency of the recycling facilities due to contamination of compostable plastic;
- Higher energy consumption required for sorting the recyclable plastic out of the collected plastic stream.
- Mechanical properties of recycled polymers may be undermined by presence of biodegradable/compostable plastics in recycled streams

This is well mirrored, for instance, in the position paper by SUEZ[130], already mentioned, which highlights the following:

[130] SUEZ (2019)SUEZ recommendations concerning Bio-sourced and Compostable Plastics

"In general, any compostable plastic mixed with recyclable plastics will reduce the mechanical properties of the recyclates. This means that it will degrade the quality and reduce the recycling opportunities. (...) An increase in the diversity and the mix of plastics only complicates sorting operations".

Ultimately, the points above may be addressed by 3 specific questions:

- What may be the acceptable presence of compostable plastics in polymers to be recycled? — It is worth noting that this more specifically refers to materials ready to be converted, hence *after* sorting at plastic sorting plants (where sorting must be performed anyway, so as to separate various types of polymers)
- What may be, in the case of increased use of compostable plastics, the likely expected percentages of compostable plastics in ordinary plastics collected for recycling, and going to sorting plants? — This may be primarily addressed through evidence available from those areas with current highest diffusion of compostable plastics.
- Will increased needs (if any) to sort compostable plastics out of recyclable plastics, likely cause an increase in costs (on account of the change in mass balances and/or more complex sorting equipment) for the plastic recycling sector?

4.3.1 Problems Related to Contamination of Compostable Plastics in Plastics Recycling

Concerning the percentage of compostable plastics that may be considered "acceptable" without undermining recycling processes and mechanical properties, this is likely to differ for various types of plastics, with particular regard to the difference between rigid and flexible plastics. This mirrors also the different fate of various types of plastics at sorting platforms.

The typical sorting scheme at sorting sites, includes;

- bag opening (if needed) and primary screening (to remove small impurities);
- ballistic separation and/or wind sifting, to separate 2-D and 3-D materials;
- optical sorting of 3-D materials; and,
- possibly, hand sorting of 2-D materials to collect large plastic films.

It should be noted that optical sorting targets specific polymers to be valued (i.e. positive identification), and not impurities to be rejected. This means the type of impurities is irrelevant. Hence, compostable plastics will behave like any other impurity i, while if mis-sorted/identified (i.e unintentionally ending up with the target materials) they may affect mechanical properties of the sorted materials.

For 2-D materials, and specifically small films (e.g. bags, packets) the issue of contamination may instead be more relevant, since 2-D impurities (e.g. compostable/biodegradable bags or flexible packaging) will finally end up in the mixed film stream, together with other polymers. However, from evidence that was collected (see further on), this is the stream which is able to incorporate higher percentages of impurities, before they become detrimental to recycling and mechanical properties of recycled materials.

Concerning rigid plastics, a study from Wageningen University on rPET[131] reported that contamination of 0.3% PLA (reflecting the contamination of 10 kg of rPET with one tray of 30 grams of PLA) in PET caused marginal effects on recycling of PET.

As stated in the Report, the concentration of PLA (and other contaminants, such as PVC, PS, PP, etc.) for the model studies;

> "…*were chosen by the industrial board, based on their industrial experience (...) to reflect realistic levels*",

which, incidentally, may be an indication of currently achievable levels of contamination in specific polymers after processing at a sorting site, based on operational experience of site managers.

In the already mentioned Report[132], the WG from CONAI also included outcomes from lab and industrial testing on mechanical, chemical and visual properties of plastic polymers blended with PLA and Mater-Bi at various mixing ratios.

In an industrial spinning test, PLA was tested in blends with rigid plastics (PET), at blending percentages (to mimic possible contamination rates) of 0.25 to 2% concluding that "*a concentration of about 1-2% of PLA in recycled PET can be managed in a common short spinning plant*".

Testing on Mater-Bi (a proprietary PBAT blend from Novamont) was performed at higher mixing percentages, to take into consideration the larger contamination that may typically be detected in flexible packaging. Mater-Bi granules were mixed with PE at mixing rates ranging from 2.5% to 20%, while Mater-Bi bags were mixed with domestic packaging films (mainly LDPE). Results showed that it was possible "*to reprocess/recycle mixtures of up to 10% concentration of Mater-Bi shoppers [bags] with conventional plastic shoppers. At higher concentrations (...) problems could arise*".

During interviews with experts from Plastics Recyclers Europe (PRE)[133], the following key points were highlighted:

- in general, they recommend staying below an average level of 2% contamination (in polymers sent to converters after sorting) to avoid any detrimental effect to mechanical recycling
- this should be considered differently for rigid plastics (with lower contamination thresholds) and for flexible plastics (where higher contamination thresholds are typical and are more acceptable)

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[131] E.U. Thoden Van Velzen, M.T. Brouwer and K. Molenveld, *Technical quality of rPET*, Wageningen University 2016

[132] CONAI, WG Biodegradable Packaging Recovery Project, *Final Report,* 2012

[133] Interviews with Chaim Gabriel Waibel, Advocacy Advisor at PRE

Interviewed experts from Plastics Recyclers Europe (PRE) concurred, in general, with the vision expressed by the ECN experts, that compostable plastics:

- should not pose problems as a tool for separate collection of organics where these are tightly connected to collection schemes. In which case they are unlikely to contaminate ordinary plastics;
- may be acceptable in what may be defined as use in "closed loops" (i.e. specific situations with trained managers, and collection planned and run accordingly, as e.g. event management when reusable is not suitable); and,
- on the contrary, it would be of high concern if there was a widespread adoption, asthis may lead to a degree of confusion for end users which can cause increased cross-contamination, and adversely impact the quality of ordinary plastics separately collected for recycling.

It may be worth mentioning that PRE also based their positions, on a particularly detailed study carried out by TCKT on behalf of EuPC[134]

The Report states that:

> "*in general, the recycling process of the different materials worked without major complications. However, there were difficulties (unsteady bubble and melt pressure varied during the extrusion process) when it came to the extrusion of new blown film with materials containing more than 5% DEG* (i.e. degradable[135]) *material*".

With regard to mechanical properties, the report states that:

> "*mechanical properties of all mixtures decreased in most cases, except the breaking elongation which showed much higher than the breaking elongation of the virgin LDPE. (...) mixtures with 50% DEG* (i.e. degradable) *material had significant lower mechanical properties. However, the visual impact and the mechanical properties already decreased at the 2 % mixtures*".

Again on films, another study by the Wageningen University[136], more specifically covering issues related to bio-based and biodegradable plastics, concluded that *"mixing up to 10% of a starch based film and up to 10% of a PLA film in a sorted plastic film mixture has no significant negative effect on mechanical properties"*, as reported in Figure 17. The bars show results in terms of percentage, relative to the reference material, shown in leftmost bars as 100% for each property.

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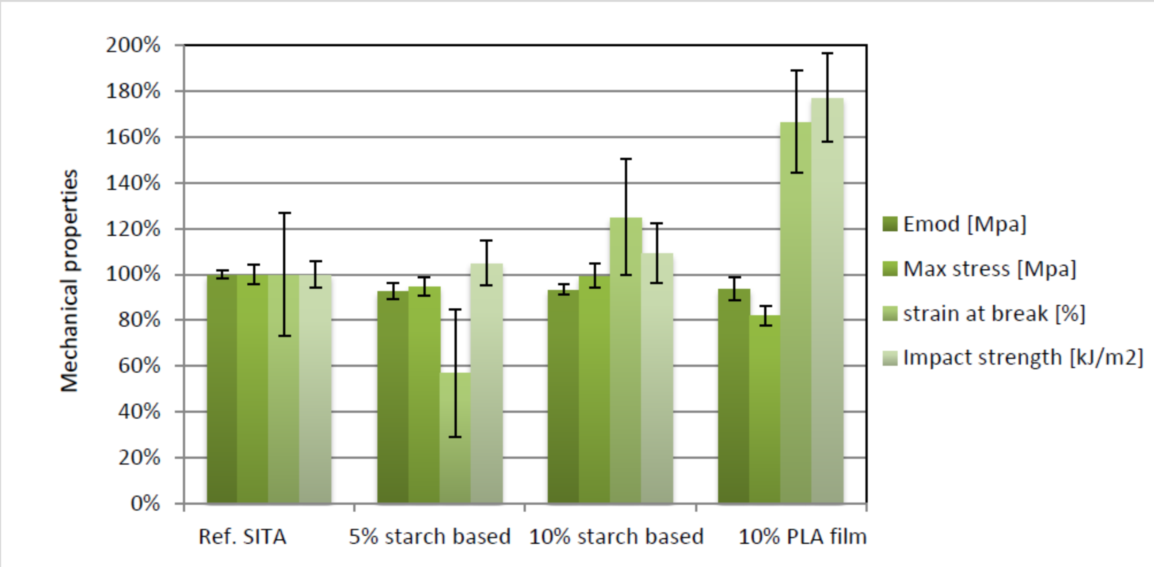
[134] Transfer Center for Polymer Technology (TCKT) on behalf of EuPC: *Impact of Degradable* and Oxo-fragmentable Plastic Carrier Bags on mechanical recycling, 2013

[135] The report unfortunately does not specify the identity of the tested materials, though in the testing scheme, some were described as "biobased and compostable" (one may assume these were complying with EN 13432, but this was not stated) and one as "non-biobased and degradable"—the reference to "oxo-fragmentable" in the title of the report, may infer that "degradable" refers to oxo-degradable plastics.

[136] M. Van den Oever, K. Molenveld, M. Van der Zee, H. Bos,, *Bio-based and biodegradable plastics - Facts and Figures,* Wageningen University, 2017

Figure 17: Effect of increased percentages of compostable plastics on mechanical properties of sorted plastic film mixture. Numbers reported as a percentage of the reference mixture



Source: M. Van den Oever et al

Worth noting that these results refer to the mixture of small-size flexible plastics (films) which in traditional operational conditions at sorting platforms is not subject to optical sorting, and only comes from mechanical separation (e.g. Wind sift, ballistic separation). Such recycling streams are inherently mixed with significant levels of PE, growing proportions of PP—which is increasingly used for small size packets— and minor but still significant percentages of PET, PVC, PS and others. Mechanical properties are therefore already influenced by the heterogeneous nature of such blends. However, this is likely to be the recycling stream where most of the compostable plastics would end up (if not organically recycled), considering the current dominance in the compostable plastics market of film-based applications (e.g. bags and packaging). The picture would change in case of increasing uses in rigid packaging, with particular reference to possible use of compostable plastics for those items likely to end up in the 3D streams at sorting platforms (e.g. trays)

In another recent and detailed study from Belgium[137] a comprehensive investigation was carried out around the impacts of the widespread use of bioplastics (therewith focussed on "bio-based", but basically also falling under the category of "biodegradable/compostable") and the potential problems this may cause in mechanical recycling, with particular (although not exclusive) regard to bottle-to-bottle recycling.

[137] L. Alaerts , M. Augustinus K. Van Acker, *Impact of Bio-Based Plastics on Current Recycling of Plastics,* in Sustainability **2018**, 10, 1487

The study investigated in a particularly detailed way the potential issues with contamination of PET bottles (hence, rigid packaging) by PLA bottles. From a comprehensive review of previous studies, the authors reported that problems start occurring from 2% contamination for degradation and yellowing, while issues with respect to transparency and discoloration may show up from a contamination rate of 0.1% or even lower. As a consequence, they considered 0.1% as the maximum acceptable contamination threshold for quality bottle-to-bottle recycling.

The authors then took into account;

- estimates for market increases of PLA bottles; and,
- separation efficiencies of optical sorters.

For proper interpretation of results, it is noteworthy that what seems to be missing from the study is the potential influence of dedicated separate collection schemes (in particular, co-collection of PLA with biowaste), which would inevitably decrease, to some extent, the contamination upfront (the study assumes all the PLA bottles to be found in the collected PET bottles).

The authors inferred a potential contamination rate, after optical sorting at 90% separation efficiency, of 0.01-0.08% by 2021; the higher end (which assumes, based on international outlooks and own estimations by the authors, a marked increase in the use of PLA bottles) is similar to the 0.1% threshold they considered as the safe level to have unconstrained rPET recycling, whilst higher levels may allow only some applications (as e.g. 5% for bottle-to-fiber).

With that in mind, the authors considered options for further removal of PLA in the recycling chain in order to assure high-quality rPET as;

- adjustment of NIR sorting equipment to decrease the number of sorting mistakes. In the author's own words, this may, however, also lead to a larger stream of rejected bottles, yields and the financial return of the recycling process;
- installation of additional NIR sorting equipment;
- separation processes exploiting low softening temperatures of PLA and based on a hot conveyor belt or a rotating drum; and,
- labelling of PLA bottles, either for the purpose of communication at the consumer level (sorting message, which brings up the potential influence of separate collection), or for instance using, chemical markers which can allow smooth detection in automatic sorting.

The authors also inferred that any of these options would lead to an increased cost for the overall recycling process, although no specific estimate was reported.

Other biopolymers that were investigated by the authors (PHA and PEF) did not demonstrate any issue of particular concern, given the fields of application (mulch films, biodegradable medical and surgical tools) and/or lower foreseen degree of uptake.

Other authors[138] investigated interference of PLA, PHB and TPS on recycling of polypropylene (PP). Recycled PP was blended with biodegradables polymers by melt extrusion followed by an injection moulding process to simulate the industrial conditions. Materials were then evaluated for changes on their thermal and mechanical performance. The authors drew the conclusions that less than 5% contamination of biodegradable polymers did not affect the overall performance of recycled PP intended for applications such as food packaging and agricultural films.

Also, experts from the Italian plastic packaging recovery organisation COREPLA[139] were specifically interviewed by the project team on the subject, so as to get more details from a situation where adoption of compostable plastics is already more widespread compared with the rest of Europe. Experts from COREPLA in particular noted the following:

- sorting is increasingly often performed in two stages:
    - a first stage "in positive" mode, aiming at selecting different targeted polymers
    - a second stage "in negative" mode so as to remove and minimise impurities from previously selected polymers
- the tendency towards adoption of two-stage sorting is unrelated to the discussed issue, but rather caused by long-term evolution of the system to become more efficient, including increasing volumes of materials that can be handled (which makes it more and more profitable to minimise impurities) and the increased quality required by converters
- more and more often, optical sorting is applied to 2-D plastics (films); this is improving the quality of recovered flexible plastics, although there is an intrinsic higher contamination even after optical sorting, on account of;
    - films overlapping each other, thereby randomly hiding some items from optical sorters;
    - films moving around between identification with NIR and being sorted out; and,
    - a structurally higher presence of contaminants, such as coupled materials, inks and dyes and food residue.

Experts from COREPLA also reported on trials performed on recycling of sorted polymers at industrial level, with LDPE packaging supplemented on purpose with various percentages of starch-based compostable plastic bags. The trials showed that beyond 4-5% compostable plastics, working with the mix became problematic.

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[138] M.D. Samper, D. Bertomeu, M.P. Arrieta, J.M. Ferri, J. López-Martínez, *Interference of Biodegradable Plastics in the Polypropylene Recycling Process,* Materials **2018**, 11, 1886

[139] Interviews with Marco Alberti Recovery Manager, and Antonio Furiano, Marketing Manager at COREPLA

Also, the experts said that in general, problems related to the presence of compostable plastics in recycled polymers are not detected, although anecdotally such problems are reported, which typically may coincide with localised campaigns that include large use of compostable plastics, beyond what may be considered an “ordinary use” (e.g. compostable bags, closed loops applications).

One technical solution to problem of correctly identifying and recycling plastics in general is ‘tagging’ via chemical tracers or digital watermarks. Diverting compostable plastics away from plastics recycling is one of the key areas that is being investigated by the Holy Grail Project[140]—a consortium of brand owners led by Procter & Gamble—which is looking into these types of technologies. The technical implantation of such solutions at scale is still to be developed, but it is a promising solution to the challenge of maximising the value from plastic recycling.

4.3.2 Occurrence of Compostable Plastics in Plastics Recycling

The results mentioned above on recycling and mechanical properties may be compared with the *actual presence* of compostable plastics;

- In post consumer plastics targeted by separate collection and going to recycling; and,
- In specific streams of sorted plastics after processing at sorting platforms

With regard to the first point, most informing evidence comes from a comprehensive research programme from Italy[141] carried out jointly by the Italian Composting Association CIC and the Plastic Packaging Recovery Organisation COREPLA, to assess cross-contamination of compostable plastics (going to recycling) and ordinary plastics (destined to mechanical recycling).

The survey included two large monitoring campaigns at sorting platforms (19 sites in 2016 and 17 sites in 2017) and consisted of roughly 1,500 compositional analyses of separately collected plastics (before sorting). This is of particular interest since Italy is typically the country with most widespread use of compostable plastics primarily as a tool for separate collection of organic waste. In Italy, this totals around 100,000 tonnes of compostable plastics marketed each year, to be compared with a total of some 2.5Mt of packaging plastics.

Results showed an average contamination rate of 0.84% compostable plastics in separately collected conventional plastics in 2016, a number which was confirmed in 2017 (0.85%). This seems to depict a situation with contamination levels compatible, (according to the studies cited in Section 4.3.1) with mechanical recycling, even before sorting, which may decrease the percentage further.

[140] https://www.newplasticseconomy.org/assets/doc/Holy-Grail.pdf
[141] M. Centemero, Accordo di programma tra Assobioplastiche, CIC, CONAI, Corepla, Resoconto sintetico delle attività di Monitoraggio, 2017

The presence of compostable plastics in specific plastic streams after sorting, is addressed by the report from Van Velzen et. Al (2016) on rPET already mentioned, which reported a typical level of 0.3% PLA in sorted PET from sorting lines. The survey from Oever et al. (2017) considered higher percentages for mixed films, and tested up to 10% compostable plastics (PLA and starch blends) in such mixtures. As already mentioned, both reports already seem to detect no detrimental effect on recycling and mechanical properties at the investigated contamination levels, which they consider “typical”.

Evidence reported from Wageningen seems consistent with info and evidence retrieved during interviews with TOMRA, producers of sorting equipment. According to experts from TOMRA[142], the following may typically be found after sorting:

- There is an increasing adoption of optical sorting also on flexible plastics
- Around or below 0.1% contamination by compostable plastics may be detected in rigid plastics after sorting
- Higher contamination rates (of around 7-8%) in plastic films, on account of primary forms and other contaminants (dies, organics, etc.) that cause a higher incidence of errors by the sorting equipment. Notably, the reported contamination is the total contamination by various polymers, with compostable plastics contributing to a minor extent (typically 0.1% in the expert’s opinion)

The study by TKCT for EuPC, though, reported some detrimental effects on plastic films at lower percentages (around and above 2%), although the following may be noted:

- The trials by TKTC were not comparing *mixed films* (as the ones coming from real operational conditions) with various percentages of compostable plastics, but *pure LDPE* with increasing percentages of compostable plastics, which should logically amplify the different properties of tested mixtures
- The foregoing is highly informing to give answers to a “what if?” question, although it may not be closely related to real operational conditions for mixed films after sorting

In fact, Oever et al. (2017) report that “*In general* [during our surveys we do] *not find bio-plastic in (sorted) post-consumer plastics and when they are found, amounts are very low”.*

This statement is also supplemented with Table 7 which shows the content of compostable plastics in more than 200 (sorted) plastic waste batches collected in the Netherlands during more than 5 years. In only 9 out of the over 200 batches bio-based plastic was found. Detected percentages in various streams after sorting were ranging from 0.008% to 0.3%, which is seemingly consistent with the “no detrimental effect” scenarios reported in tests on mechanical properties.

[142] Interviews with Juergen Priesters, Business Development Directoor at TOMRA Sorting GmbH

Table 7: Bio-plastics found in (sorted) plastic waste in various batches analysed over a 5 year period.

Waste type	Bioplastic type	Share of (%wet weight)
Mix DKR-350	Starch film	0.12%
PLA	PLA film	0.14%
Film DKR-310	PLA film	0.008%
Film DKR-310	PLA film	0.01%
Rigid plastics	Starch film	0.02%
Municipal Solid Waste	PLA & PUR	0.3%
HDPE	Starch blends	0.03%

4.3.3 Key Conclusions

Key Conclusions – Establishing the effect of biodegradable/compostable plastics entering plastics recycling streams

Contamination from compostable plastics in plastics sent for recycling, may vary from material to material, and tend to be lower for rigid plastics, higher for flexible plastics. The type of end recycled product also effects how detrimental this contamination is—PET recycling for food grade applications is highly sensitive, whereas plastics destined to be recycled into fibres are less affected.

Processes at sorting platforms tend to reduce the level of contamination in any given stream targeted for recycling. This is typically more effective for optical sorting (which typically targets rigid plastics) while it shows less effective for mechanical separation (mixed films). In both cases, reports indicate that final levels of contamination are compatible with subsequent recycling, although this refers to a scenario in which compostable plastics are only widespread in niche applications. More widespread use in packaging—particularly if more rigid packaging is used— may require adaptation of the sorting lines, or generate levels of contamination that may cause problems to mechanical recycling. The use of innovate technologies for 'tagging' plastics via chemical markers or water marks may also be employed for compostable plastics and would reduce the risk of contamination should the market increase to a point where these materials are deemed problematic.

In Italy, where there is already widespread use of compostable plastics (~50% of the EU market) the overall contamination rate is below the levels considered to be of concern for mechanical recycling before sorting. Operational design of sorting platforms are effective in ensuring these end up in "rejects" alongside other low-value plastics (e.g. from optical sorting of rigid plastics). That being said, Italy still mostly uses compostable plastics for niche applications, e.g. compostable bags for separate collection and tableware in “closed loops”; a more widespread application beyond these boundaries may result in different outcomes which has yet to receive any significant research.

4.4 The Risk of Littering Biodegradable Plastics

There has long been concern that littering may be increased where a product claims to be ‘biodegradable’ in the open environment due to the assumption that some or all of the impacts of littering are avoided.

There is generally a lack of recent evidence and surveys as it is likely that attitudes may have changed in recent years due to an increased awareness of plastic pollution. A focus groups from Scotland in 2007 showed that most participants felt that it was acceptable to litter ‘biodegradable’ items as these were seen as harmless – although participants did not distinguish between organic food waste and biodegradable plastics.[143] This study appears to suggest that the driver for littering is not apathy, but misinformation.

However, only 19% surveyed for a US study thought it was understandable to litter if the item was biodegradable or could rot away although one group thought it was a commonly held view that cigarette butts were biodegradable and acceptable as a form of litter.[144] Another survey on the reasons why smokers litter cigarette butts, documented that some respondents believed that cigarette butts are different to other types of litter, for reasons including that it was believed that cigarette butts are biodegradable.[145] An analysis of tobacco industry focus groups found evidence that tobacco companies thought that biodegradable filters might encourage littering.[146] Because the tobacco industry also thought that biodegradable filters ‘may not degrade as quickly as smokers really want’; recognising that ‘all discarded filter tips look alike to the public’, an increased or static litter rate, and the fact that biodegradable filters would highlight the fact that the degradability of filters generally was an issue, would run counter the desire of industry to improve their public perception.

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[143] Keep Scotland Beautiful (2007) Public attitudes to litter and littering in Scotland, *cited in* Brook Lyndhurst (2013) *Rapid Evidence Review of Littering Behaviour and Anti-Litter Policies*, Report for Zero Waste Scotland, 2013, http://www.zerowastescotland.org.uk/sites/files/zws/Rapid%20Evidence%20Review%20of%20Littering%20Behaviour%20and%20Anti-Litter%20Policies.pdf

[144] S. Groner Associates (2009) *Littering and the iGeneration. City-Wide Intercept Study of Youth Litter Behavior in Los Angeles.*, Report for Keep Los Angeles Beautiful, 2009, http://www.cleanup-sa.co.za/images/Littering%20and%20the%20iGeneration_Youth%20Litter%20Study%20for%20KLAB%20.pdf

[145] ENCAMS (2008) *No Butts. Smoking-Related Litter*, 2008

[146] Smith, E.A., and Novotny, T.E. (2011) Whose butt is it? tobacco industry research about smokers and cigarette butt waste, *Tobacco Control*, Vol.20, pp.i2–i9

This raises the interesting issue of the public's perception of the timescales for biodegradation. In the open environment this would be difficult, if not impossible to guarantee. There is also an indication from the tobacco industry study that the expectation would be for weeks or months rather than years (which is a more realistic timeframe) – if a piece of litter is still present months later, it still creates a visual disamenity during that time.

However whether the belief around the increased or equivalent littering of biodegradable cigarette filters can be extended to other types of litter perceived as degradable is not known with certainty: as mentioned cigarette butt litter is frequently perceived as in a different league to other types of litter such as bottles, cans or potentially bags of any type, because cigarette butt litter is relatively small and less conspicuous. The deliberate littering of plastic items—whether marked as biodegradable or compostable—may also have different connotations when compared to a small fibrous product made from bio-based ingredients.

A more recent focus group from Scotland again revealed similar responses and states that [147]

> *"For some participants, the idea of 'degradability' makes litter [of fruit cores and skins] feel less unacceptable; a few people also mentioned this characteristic in relation to plastic bags or paper."*

The report concluded that whether something is considered biodegradable was a "consistent criterion" for prioritizing litter clear-up.

In response to the question, "I'm more likely to litter when the item I'm holding is biodegradable", 22.6% of the respondents agreed or strongly agreed, while the remainder, 77.4% disagreed or strongly disagreed. Those who agreed to any extent scored more highly with regard to self-reported littering behaviour, suggesting that perhaps the propensity for biodegradable litter to promote littering behaviour is greater amongst those that are already more likely to litter.

The caveat to any survey or focus group based study is that reported 'hypothetical' behaviour is difficult to correlate with actual behaviour, for which empirical observations are necessary. There is also an issue with the term 'biodegradable' which is often used is such studies, but it lacks a common agreement on meaning and does not reference a particular material or product – for one individual this may mean an apple core and for another, a paper bag for example.

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[147] Brook Lyndhurst (2015) *Public Perceptions and Concerns around Litter*, Report for Zero Waste Scotland, 2015, http://www.zerowastescotland.org.uk/sites/files/zws/Litter%20Insights%20final%20web%20March%2015.pdf

More recently a summary of two German focus groups on the perceptions of bioplastics found that:[148]

> *"..the actual timeframe a product needs to biodegrade totally differs from what consumers assume. Marine littering had been addressed as one of the major concerns about petro-based plastics. Some participants hoping bioplastics promised to provide a solution to marine littering were shocked and disappointed to learn that not all bioplastic products – actually most of them – are biodegradable or biodegrade outside of a composting facility."*

This addressed the wider issue that the term *bioplastic* is also often synonymous with *biodegradable* or *compostable* plastic. As none of these terms are standardised it allows communication and consequently understanding of these terms to differ vastly.

As there is a distinct lack of concrete evidence, it is also worth looking more widely to studies that investigate the psychology around environmental behaviour in general. A meta analysis of such behaviour[149] from 2013 suggests that behaviour is influence by a large number of factors both internal and external. Existing attitudes, personal and social norms, and perceived behavioural control are all considered as drivers for specific behaviours – this supports the notion that littering is more likely to take place if predisposed to such behaviour. The marketing or a product as 'biodegradable' may just be the trigger to act accordingly and potentially remove any negative social connotations — the lower the perception of responsibility and capability to address an issue, the less likely a person is to take (positive) action.

4.4.1 Key Conclusions

Key Conclusions – The Risks of Littering Biodegradable Plastics
• There is a lack of recent conclusive empirical evidence that clearly correlates the marketing of biodegradable/compostable plastics with an increase in the tendency to litter - further research is needed. • Several studies point towards a perception amongst consumers that 'biodegradable' or 'compostable' is a virtuous aspect of a product and that littering such an item would be less impactful. • Some related empirical evidence—on environmental behaviour in general—suggests that labelling a product with 'biodegradable' may be seen by some people as a technological solution removing responsibility from the individual. This may increase the tendency for those already predisposed to litter these items.

[148] Haider, T., Volker, C., Kramm, J., Landfester, K., and Wurm, F. (2019) Plastics of the future? The Impact of Biodegradable Polymers on the Environment and on Society, *Angewandte Chemie International Edition*, No.58, pp.50–62

[149] Klöckner, C.A. (2013) A Comprehensive Model of the Psychology of Environmental Behaviour—A Meta-Analysis, *Global Environmental Change*, Vol.23, No.5, pp.1028–1038

- There is also evidence suggesting that perceptions of the time for such plastics to biodegrade are likely not in line with reality and overall, actions are not always based upon correct information.

5.0 Review of EN 13432

One of the key issues when discussing compatibility of compostable plastics with the composting sector, is codifying their fitness for composting.

The need for a codified standard, was first addressed after the adoption of the Packaging and Packaging Waste Directive (PPWD) 94/62/EC, in that the Directive acknowledged composting and anaerobic digestion as "organic recycling", and introduced the Essential Requirements where the concept of "packaging recoverable in the form of composting" was included.

As a consequence, CEN was requested in 1996 to prepare standards to assess suitability of packaging for such processes. The standard EN 13432 on compostability in industrial composting, was approved and published in 2001. EN 13432 has subsequently undergone three reviews (in 2005, 2010 and 2015) with no changes. It is now the standard that signifies compliance with the Essential Requirements for compostable packaging under the PPWD.

The standard's specific requirements are assessed to see whether any issue of reliability or any cross implication with operational conditions at processing sites may cause problems.

The standard includes on the following key requirements:

- **Analysis on chemical composition**. The key requirement here is that heavy metal content be kept below specific threshold values. Limit values are based on the Community Eco-label for soil improvers from 1998[150] (although these values are still used in the current 2015 version), and are set at 50 % of the maximum concentration required by the Eco-label. The rationale for this (already discussed) assumes 50 % of the original weight of the material will remain in compost after biological treatment together with the complete original amount of hazardous substances. This requires that the theoretical final concentration in the composted compostable plastics should not exceed the maximum allowable concentration defined in the EU Eco-label.
- **Biodegradability**, which must be measured through a lab test method (ISO 14855: biodegradability under controlled composting conditions). In order to show complete (intrinsic) biodegradability, a biodegradation level of at least 90% must be reached in fewer than 6 months. A separate test is defined for degradability under anaerobic conditions (which is relevant to processing in anaerobic digestion sites). The anaerobic test lasts 2 months and the requirement

[150] COMMISSION DECISION (EU) 98/488 of 7 April 1998 establishing the ecological criteria for the award of the Community eco-label to soil improvers

is 50% biodegradation; the standard also states that that this lower threshold is because *"in **all** commercially available biogasification [AD] plants the process scheme provides a short second aerobic stabilization phase in which the biodegradation can further continue."* Evidently it is not that case that *all* plants undergo the step and, in many countries, the opposite is true.

- **Disintegration**: final compost after 12 weeks is screened with a 2 mm sieve. The mass of test material residues with dimensions > 2 mm shall be less than 10% of the original input.
- **Eco-toxicity**: performed on the compost produced with compostable plastics inside the input feedstock. The test, performed through germination tests according to test method OECD 208, verifies absence of negative effects on plant growth.

With reference to the they key requirements, Table 8 describes some of the important issues and criticisms that have been uncovered throughout this study and some of the potential solutions to these. These are largely focused on the issues around the biodegradation and fragmentation tests not being reflective of all composting/AD practice.

Table 8: Assessment of EN 13432 Criticisms

Criticism	Problem	Discussion	Potential Remedies	Problems with Remedies
Aerobic biodegradation test duration is too long **(6 months)** **Duration of the test on disintegration is too long** **(12 weeks)**	Instances of the plastic remaining visible in the compost at the end of the treatment process which for some countries means compost quality standards cannot be met	As the test is to determine 'inherent biodegradability' under *ideal conditions* it can be argued that the test duration should not be directly related to real life. Other inherently biodegradable materials, such as lignin (typically anything wood-like in garden waste), would show a much lower degradation rate in the 6 months and, if subject to the test, would not pass it. Hence, the duration of the test may be intended to show the highest possible biodegradation during the testing time. The Presence of visible fragments, in the case of shorter composting times, may undermine the marketing value of compost. Larger fragments, that may still persist after shorter composting times, may be screened out, thereby increasing the amount of rejects.	Reducing the time pass threshold	Potential exclusion of materials in countries that already process in line with the standard (e.g. Italy) Product quality and specification reduced as thinner material is required to pass the test
			Composting facilities to meet the time requirements	The composting process is driven by the need to process organic waste and the output quality governed by individual Member States' agronomic requirements. The requirements of compostable plastics should not be the driving force.
			Require soil (or low temperature) biodegradation testing for residual un-degraded material	There is additional time and cost for verification and it would be unclear what state the material should be in for testing. Introducing such requirements may restrict the use to materials that only biodegrade at high temperatures. This may only be helpful for countries that do not currently have organic waste treatment systems that reflect the requires of the standard.
The assumptions in the anaerobic biodegradation test do not reflect reality	The anaerobic biodegradation test does not reflect real life practice and assumes a secondary composting stage.	Effectively the Standard only applies to a compost output, not a digestate output. In reality only some EU Member States use post-composting of digestate where there is a requirement to meet the End of Waste criteria (e.g. Italy) while there are many sites elsewhere that do not include post-composting, since national regulations allow direct land spreading of digestate (e.g. Germany, UK and Scandinavian Countries). Testing under AD	Require a specific, dedicated post-composting stage for the plastic rejects	This is an operational change that cannot be dictated by the Standards and may only be cost effective if a plant is receiving high amounts of compostable plastics

	Anaerobic testing is also not a requirement	conditions is also not a strict requirement which is problematic for countries that process organic waste in this way.	Adapt testing for biodegradation requirements without the assumption of secondary composting	This may be questionable on agro-environmental grounds — post-composting ensures full stabilisation, minimises residual phytotoxicity, avoids release of fugitive methane and ammonia, with the latter being a precursor for secondary nanoparticulate. It is also unclear whether materials would pass such a test

5.1 Recommendations for an EN 13432 Update

In order for the requirement for EN 13432 compliance be effective it is also recommended that the standard (and consequently EN 14995) be updated to reflect the latest scientific understanding and approaches. Currently these are best reflected in the draft CEN standard for home composting of carrier bags (detailed in the following Section 8.4.3) that includes the additional aspects which could also strengthen testing and requirements for industrial composting:

- A requirement to **separately test and meet the criteria for biodegradation of all organic constituents**[151] which are present in the material at a concentration between 1% and 15% — thereby removing the potential for non-biodegradable constituents to be used in large proportions in the product.
- The **introduction of a nitrification inhibition test and an earthworm toxicity test** (these are also requirements specified in the recent EU fertiliser Regulation amendments and EN 17033 on biodegradable mulch films, therefore are already recognised as important for agriculture applications).[152]
- A requirement that substances of very high concern (SVHC) and those on the candidate list shall not exceed a concentration limit of 0.1 % in the material of the product.[153]

Reducing the time threshold for aerobic composting is potentially problematic and risks penalising countries that already successfully work within the Standards. The concept of testing for 'inherent biodegradability' is also important as the Standards are not designed to replicate the process exactly – however they should provide assurance that the product will perform as expected. This is the major weakness of Standards that are designed to be applied across the EU (and many more countries across the world have also adopted), but can never truly reflect every circumstance. Changing the Standards to reflect all practises is impractical and therefore it is recommended that Member States conduct their own trials to determine whether the Standard is fit for the purpose of verifying that compostable plastics perform as required (noting that 'performance' is a relative term that will be dictated by the local process and compost quality requirements). This will help in determining whether they should accept compostable plastics or not in their biowaste treatment facilities and what changes need to be made to do so in the future (if desirable). Any suggestion to amend the timescale should be undertaken in consultation with organic waste processors representing the different technologies and techniques which are used throughout the EU. The Standards should then provide more guidance of where they are or are not applicable.

[151] Chemical constituent that contains carbon covalently linked to other carbon atoms and to other elements, most commonly hydrogen, oxygen or nitrogen.
[152] REGULATION (EU) 2019/1009 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019R1009&from=EN#d1e40-1-1
[153] This also includes those on the candidate list - https://echa.europa.eu/candidate-list-table

It is also not a strict requirement of EN 13432 that biodegradability under anaerobic conditions is determined and the assumption that there is always a secondary composting stage is also incorrect. This demonstrates that that standards are not a reliable way of ensuring that compostable plastics are performing effectively in anaerobic organic waste treatment. There is no clear way forward in this regard as the solutions are largely operational and cannot be driven by this standard. Making the anaerobic biodegradation test an obligatory part of meeting EN 13432/14995 may go some way to improving this, but it is unclear how representative the current test is. Another option is to create a separate AD standard which Member States could make a mandatory requirement for compostable plastics in their country. Creating multiple Standards may add to confusion, rather than solve this issue, however. The Standard would likely still include an expectation of a secondary composting stage; the current issue of the Standard being erroneously applied in situations where this stage is not practiced may still, therefore, be a problem.

There is also still an outstanding question around the issue of residual fragmented compostable plastics in the compost/digestate. These are likely to be in the microplastic size range as both the disintegration tests and many country compost quality requirements have a limit of 2mm. The visual aspect is not so important for farmers, who are more concerned with functional performance.[154] Introducing stronger toxicity tests as described above will help, here. However, there may be merit in introducing a test to validate the biodegradation performance in soil. The current tests only validate inherent biodegradability at higher temperature and as there are different microorganisms present that are active at different (lower) temperatures, this cannot be guaranteed in soil. As described later on in this report (Section 8.3.4.2), with regard to home composting, not all materials will also biodegrade at low temperatures as they require a thermal trigger to start hydrolysing.

The French government have also recognised this issue with a recent amendment in law[155] to require any product that wants to be described as 'compostable' must also conform to the country's home composting standard. The implications of this amendment are yet to be seen (e.g. some product types and compostable materials effectively being restricted), but in countries where the organic waste system is not capable of guaranteeing the full biodegradation of compostable plastics, these sorts of stronger requirements may be necessary. The amendment is also aimed at reducing consumer confusion around terminology.

A further additional proposed requirement stems from the example of a single-use coffee pod. It is reported that these products may disintegrate faster in their pure material form compared to the product form post use (i.e. including the used coffee and

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[154] Perchard D (2005) CEEES workshop, biodegradable polymers-where are the limits, 3 November 2005. CEEES-confederation of the environmental engineering societies. http://www.ceees.org/auxiliary/biopolymer051103.pdf

[155] http://www.assemblee-nationale.fr/dyn/15/amendements/2454/AN/1181

with the lid pierced)—this holds true with the known phenomenon that increasing the surface available to the microorganisms speeds up biodegradation.

Whilst some laboratories that test these items already test in this form, it is recommended that this is codified in the standard to ensure this practice is universal.

6.0 Environmental Performance of Compostable Plastics

6.1 Environmental performance of alternative non-plastic biodegradable products compared with compostable plastic

Non-plastic biodegradable products such as paper can often be used to fulfil the same function as compostable plastics. The environmental performance of these products compared with compostable plastics are investigated in this chapter. There is limited literature comparing compostable plastic products to non-plastic biodegradable products.

6.1.1 Paper Carrier Bags

One on the most widely used and discussed plastic products, carrier bags, has been studied through comparative LCA comparing carrier bags for groceries made from paper and compostable plastic.

Research by Bisnella, Fruegaard Astrup & Damgaard[156] compared grocery carrier bags made from LDPE, paper, bleached and unbleached, and starch-based plastic among others. The functional unit of this study was:

> *"Carrying one-time grocery shopping with an average volume of 22 litres and with an average weight of 12 kilograms from Danish supermarkets to homes in 2017 with a (newly purchased) carrier bag. The carrier bag is produced in Europe and distributed to Danish supermarkets. After use, the carrier bag is collected by the Danish waste management system"*[156].

In the study one plastic LDPE bag was needed to fulfil the functional unit whilst it required two craft paper bags and two compostable plastic bags. The study did not consider composting or biological treatment of the compostable plastic bag nor the paper bag, since materials other than organic waste are generally not treated with biological waste treatments in Denmark. Two end of life scenarios were modelled for the

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[156] Bisinella, V. A., Fruergaard Astrup, T., & Damgaard, A. (2018). *Life Cycle Asessment of grocery carrier bags.* The Danish Environmental Protection Agency.

starch-based bags; 1) direct incineration and 2) function as a waste bag for municipal waste and consequently incinerated. Three EoL scenarios were modelled for the paper bags 1) direct incineration and 2) recycled 3) function as a waste bag for municipal waste and consequently incinerated. For both bags the best EoL scenario was to function as a waste bag and be incinerated with the municipal waste. If the carrier bag is used as a waste bag it will avoid the production of a thin fossil plastic waste bag. The results showed that the paper bag performed better than the compostable plastic bag in 11 out 15 impact categories considered, including climate change. Both the paper bag and the compostable plastic bag performed better than the fossil LDPE bag in the impact category of climate change. In general, LDPE carrier bags, were found to provide the lowest overall environmental impacts when not considering reuse.

The study of Chivancik-Uslu, Puig, Hauschild, Fullana-i-Palmer[157], compares different carrier bags by applying both a classic LCA and by assessing the risk of littering of each bag. The functional unit of the study was:

> *"To facilitate the transportation of purchased food and drinks to an average household for one year, from the point of sale to the place of consumption*[157]*"*

The number of bags included in the functional unit were 408 per year for both the compostable plastic bag and the paper bag, assumed 204 purchases and 2 bags per purchase. The waste management distribution represents the generic Spanish waste system. The modelled EoL for the paper bag was 57% recycling, 4.4% incineration and 38% landfill. For the compostable plastic bag, the EoL applied was 17% incineration and 83% landfilling. The results showed that the compostable plastic bag had lower environmental impacts in 7 out of 8 impact categories considered, compared to the paper bag. The paper bag had a lower impact for water use. The compostable plastic bag had a climate change impact of 145 kg CO_2/FU (functional unit) and the paper bag 295 kg CO_2/FU. Comparing the compostable carrier bags (both paper and plastic) to a regular LDPE carrier bag, the LDPE carrier bag performed better in most impact categories, however, in terms of risk of littering both compostable alternatives showed a lower risk of littering.

Edwards & Fry[158] performed an LCA on carrier bags from paper and starch-polyester blend that is compostable. The functional unit of the study was:

"Carrying one month's shopping (483 items) from the supermarket to the home in the UK in 2006/07".

To fulfil the functional unit a total of 82 starch-based bags were needed compared to 65 paper bags. The baseline EoL scenario is 14% incineration and 86% landfill, which was the average distribution for municipal waste in the UK in 2006. The results showed that

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[157] Civancik-Uslu, D., Puig, R., Hauschild, M., & Fullana-i-Palmer, P. (2019). Life cycle assessment of carrier bags and development of a littering indicator. *Science of the Total Environment*, 621-630.
[158] Edwards, C., & Fry, J. M. (2011). Life cycle assessment of su-permarket carrier bags: a review of the bags available in 2006. Report: SC030148. UK Environment Agency.

the compostable plastic bag had a lower climate change impact compared to the paper bag, respectively 4.2 kg CO_2/FU and 5.5 kg CO_2/FU. For other impact categories the compostable plastic bag performed better than the paper bag in; abiotic depletion, acidification, human toxicity, terrestrial ecotoxicity and photochemical oxidation, but worse in fresh water ecotoxicity, eutrophication and marine ecotoxicity.

The climate change impact of the compostable plastic carrier bag was lowered to 3.3 kg CO_2/FU with composting solely as EoL treatment. Composting of the paper bag however only lowers the climate change impact to 5.4 kg CO_2/FU. The starch-based bag has higher impacts from methane generation in landfilling than the paper bag. The environmental impact is dominated by resource use and production stages. Transport, secondary packaging and EoL management generally have a minimal influence on the environmental performance. Comparing the compostable carrier bags (both plastic and paper) to a HDPE carrier bag the results show that the HDPE bag has lower environmental impacts in most impact categories. The study therefore concludes that the conventional HDPE bag has the least environmental burden.

6.1.2 Packaging Film from Wheat Gluten

Deng et al.[159] carried out a comparative LCA for packaging film made from wheat gluten powder, PLA and LDPE. Wheat gluten is a co-product from production of wheat flour. The bio-based compostable packaging films struggle to achieve a low water vapor permeability and are therefore less suitable in packaging were a moisture barrier is needed. The functional unit of the study is 1 m^2 packaging film with 0.15mm thickness.

The results with incineration as EoL scenario for all packaging films show that the wheat gluten film has a much lower climate change impact (2,015 kg CO_2/FU) compared to both PLA (584 kg CO_2/FU) and LDPE film (561 kg CO_2/FU). For other impact categories the wheat gluten packaging film showed higher impacts compared to the PLA film in 10 out of 18 impact categories considered.

The production of the packaging film is the life cycle phase contributing to most impact categories for wheat gluten film and PLA, for LDPE the direct emissions from incineration contributes most to the climate change impact. The wheat gluten film uses 75% less non-renewable energy compared to PLA but gets less benefits from incineration.

The study reports that windrow composting and incineration with energy recovery are comparable for the majority of the impacts assessed. For both PLA and wheat gluten packaging film the biological treatment of industrial composting does not offer substantial benefits over incineration.

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[159] Deng, Y., Achten, W. M., Van Acker, K., & Duflou, J. R. (2013). Life cycle assessment of wheat gluten powder and derived packaging film. *Biofuels, Bioproducts and Biorefining*, *7*(4), 429-458.

6.1.3 Key Conclusions

Key Conclusions – Environmental performance of alternative non-plastic biodegradable products compared with compostable plastic
The three reviewed carrier bag studies show different results when comparing paper and compostable plastic carrier bags. Two out of the three studies find that the compostable plastic bag has generally lower environmental burdens compared to a paper bag. On the other hand, one study concludes the paper bag performs better than the compostable plastic bag. However, all three studies concluded that conventional non-compostable fossil carrier bags have a lower environmental impact than alternative bio-based compostable carrier bags in most impact categories. The three studies represent three different EU Member State waste management systems, however none of the studies include biological treatment as a baseline scenario for compostable carrier bags. This is a particular weakness given that these materials are designed to be composted and demonstrates some of the issues with the way in which current LCAs have been conducted for these materials—this includes the lack of scenarios for reuse as a biowaste bag. The study on packaging film shows that in some impact categories the non-plastic alternative has a lower environmental impact and in other impact categories the compostable plastic performs better. It can be concluded that there is no clear evidence that non-plastic biodegradable alternatives are environmentally preferable to compostable plastics.

6.2 Environmental performance of compostable plastics from an LCA perspective

LCAs are calculated based on a specific scope, methodology, system boundary and data quality. These factors vary between LCAs and therefore it can be misleading to compare and/or aggregate findings from different LCAs. In this section the results of two JRC studies with a number of LCA case studies are briefly described.

The JRC published a draft report "Environmental sustainability assessment comparing through the means of lifecycle assessment the potential environmental impacts of the use of alternative feedstock (biomass, recycled plastics, CO_2) for plastic articles in comparison to using current feedstock." in 2018 with the aim to develop a consistent and appropriate methodological approach to better understanding the life-cycle impacts of alternative feedstock for plastics production. The first part of the report contains a review on the existing literature comparing conventional plastic with plastics from alternative feedstocks and proposed methodological requirements. The report identified 32 studies that met the defined quality criteria and level of detail. These studies were scrutinized based on methodological approach and relevant aspect for LCAs on plastics and bio-based plastics, such as EoL, littering, inclusion of land use changes, multifunctionality, biodegradation etc. Looking into the types of compostable plastics covered, corn as feedstock and PLA as plastic type were the most addressed types in the studies. Out of the 32 studies, 14 studies included analysis of different EoL options, and 13 studies included an in-depth analysis of biodegradation in the EoL phase[160]. The biodegradation of PLA in industrial composting varied between 44% and 95% while for starch-based plastics the variation was between 60% and 91%. Regarding the overall modelling of biodegradation in biological waste treatments (industrial composting and anaerobic digestion (AD)) the focus is mostly on the fate of carbon and nitrogen during treatment and subsequent land application of the residual composted or digested material. However, the fate and impacts of any non-degradable element or compound in the compostable plastics (e.g. metals and additives) is usually not addressed. This might be due to lacking information on full product composition and use of additives.

The second part of the report by the JRC contains LCAs comparing compostable bio-based plastic with conventional fossil-based plastic carried out with the proposed methodology on beverage bottles and packaging films. The results of these LCAs are summarized below:

6.2.1 Packaging Film

The materials assessed are starch-based film, PLA film, PP, LDPE and bio-based LDPE. The feedstock for the PLA film was corn cultivated in USA. The functional unit is 100 m^2 of food flexible packaging film with an average thick-ness of 30 µm and ensuring a similar overall shelf life of the packaged product. The EoL was based on average EU waste management; for the compostable packaging film (PLA and starch-based) 31% was landfilled, 39% incinerated, 27% industrial composted and 3% anaerobic digested. For the fossil-based packaging films 31% was landfilled, 39% incinerated and 30% recycled. The results show that compostable packaging films (starch and PLA) have lower impacts than the reference PP film in several impact categories and higher impacts in others. It therefore depends on the importance of each impact category if the PLA and starch-based alternatives can be considered to have lower environmental burden. The starch-based film had the highest climate change impact due to high emissions from landfilling. For all materials types the polymer production (including feedstock cultivation) is the life cycle phase contributing to the highest share of emissions, followed by the EoL stage. The study shows that the biodegradable film alternatives (PLA and starch-based), show no general advantages compared to PP when biological treatment options (industrial composting and AD) are considered individually.

[160] Nessi, S., Bulgheroni, C., Konti, A., Sinkko, T., Tonino, D., & Pant, R. (2018). Environmental sustainability assessment comparing through the means of lifecycle assessment thepotential environmental impacts of the use ofalternative feedstock (biomass, recycled plastics,CO2) for plastic articles in comparison to usingcurrent feedstock. The European Commission - Joint Research Centre (JRC).

6.2.2 Beverage Bottles

A conventional PET beverage bottle is compared with other plastic material, were PLA, made from corn from USA, is the only compostable material. For PLA it was assumed that the EoL was divided into 30% recycling, 27% industrial composting, 3% AD, 20% incinerating and 20% landfilling. The PET bottle was assumed 60% recycled, 20 incinerated and 20% landfilled. The PLA beverage bottles show an environmental advantage in the resource impact categories and the three toxicity related impact categories. However, for the other 11 impact categories including climate change the PLA bottles perform worse. The polymer production (including feedstock cultivation) is the life cy-cle stage were above 50% of the environmental impacts occur, the EoL stage only contains 3-14% of the impacts. Focusing on compostable PLA, no overall advantages are found when biological treatment options (composting and anaerobic digestion) are considered individually and no substantial changes occur in the comparison with fossil-based non-biodegradable materials. Therefore, when proper waste collection can be achieved, the use of compostable materials for beverage bottle production does not represent, a solution to achieve an improved environmental performance compared to conventional fossil-based materials, especially if these come from recycled feed-stock.

In 2018 the European commission published another report "Environmental impact assessments of innovative bio-based product. Task 1 of Study on Support to R&I Policy in the Area of Bio-based Products and Services"[161]. The report contains several LCAs on bio-based plastic products (both compostable and not) compared with their fossil conventional counterparts. The temporal scope was from 2019 and 5-10 years forward, the modelling was based on a cradle-to-grave LCA and the geological scope was Europe. The EoL modelling was therefore based on average EU waste technologies but EoL scenarios for single different waste treatments were also analysed. Littering was not included in the modelling which is one of the uncertainties of this study. The study includes six LCA case studies of compostable plastic two of the most relevant case studies for this project are highlighted below.

6.2.3 Packaging Films

The three materials assessed in the LCA were PLA, PP and bio-based PP. The feedstock of PLA was a market average mix made from corn cultivated in the United States and sugarcane from Thailand. The LCA was modelled with the assumption that 15 kg of food waste will follow per kg of plastic disposed. The weighted results with toxicity and average EU EoL show that the PLA packaging film has a lower weighted score, hence it is the preferred choice. The difference in the scores is only 10 % and a small change in the prerequisites can influence which product system is environmentally preferable. The EoL

[161] COWI A/S , Directorate-General for Research and Innovation (European Commission) , Utrecht University. (2019). Environmental impact assessments of innovative bio-based product. Task 1 of “Study on Support to R&I Policy in the Area of Bio-based Products and Services “ - Study. European Commission.

phase had a large contribution in most impact categories, mostly due to the additional food waste considered.

6.2.4 End Of life

The end of life of compostable/biodegradable products is an area that is generally problematic to model in LCA and there is no established methodology for doing so. There is little empirical data that can be used for processes such as landfill and composting—these are particularly difficult to effectively measure emissions from in a reliable way and it is even more difficult to attribute these to specific materials. Results are highly dependent upon system boundaries, scope, data limitations and critical assumptions, such as EoL and biodegradation[162,163,164.]

Table 9 summarises the current understanding of the various end-of-life treatment methods for compostable plastics in comparison to conventional plastics. It is possible for compostable plastics breaking down in landfills to produce methane, but the specific evidence for this is mixed as landfills are heterogeneous, complex environments. A 2011 study using the relatively obscure material PHBO found that it did emit methane in simulated landfill conditions.[165] A study conducted on behalf of Natureworks—a global PLA producer—found the opposite[166], but an independent study focusing on PLA found that some methane is produced from PLA when temperatures of 55°C are reached, which is common in landfills with a high organic content.[167] The composition of the landfill will also highly influence this and all three studies are from the USA which has less strict rules around what can be landfilled than the EU.

However, logically if the materials biodegrade in anaerobic digestion, one would expect similar in the anaerobic conditions in landfill which will be partly down to whether the correct microorganisms are present. As discussed previously in Section 4.2.1.1, the ability to biodegrade in anaerobic conditions is also dependent on the material and therefore blanket statements cannot be made one way or the other in this regard.

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[162] Gironi, F., & Piemonte, V. (2011). Bioplastics and petroleum-based plastics: strengths and weaknesses. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33(21),*, 1949-1959.

[163] Hottle, T. A., Bilec, M. M., & Landis, A. E. (2013). (2013). Sustainability assessments of bio-based polymers. *Polymer Degradation and Stability, 98(9),* , 1898-1907.

[164] Yates, M. R., & Barlow, C. Y. (2013). Life cycle assessments of biodegradable, commercial biopolymers—A critical review. *Resources, Conservation and Recycling, 78*, 54-66.

[165] Levis JW and Barlaz MA (2011), Is biodegradability a desirable attribute for discarded solid waste? Perspectives from a national landfill greenhouse gas inventory model. Environ Sci Technol, 03/05/2019 https://www.ncbi.nlm.nih.gov/pubmed/21615182

[166] Kolstad, J.J., Vink, E.T.H., De Wilde, B., and Debeer, L. (2012) Assessment of anaerobic degradation of Ingeo™ polylactides under accelerated landfill conditions, Polymer Degradation and Stability, Vol.97, No.7, pp.1131–1141

[167] Max J. Krause, and Timothy G. Townsend (2016) Life-Cycle Assumptions of Landfilled Polylactic Acid Underpredict Methane Generation, *Environmental Science & Technology Letters*, Vol.3, p.166−169

Conventional plastics are inert and hence produce no GHG (and arguably act as carbon storage).

Incineration is more straight forward as both compostable and conventional release their locked up carbon as CO_2 when burned. However, the province of the carbon that is released is important in this instance. From a purely end-of-life point of view the short cycle biogenic carbon released from bio-based plastics is generally considered to be less impactful (even carbon neutral) than releasing older fossil carbon. Of course, the wider the full life cycle impacts should be considered before declaring that bio-based material is superior from a climate change point of view.

The comparison between incineration with composting often one the key deciders in LCA studies that focus on compostable plastics. A study by Rossi, Dubois, Humbert & Jolliet[168], on European EoL options for bio-based compostable films of PLA and thermoplastic starch (TPS) found that composting did not lead to environmental savings compared to incineration, but AD performed similarly—the assumptions around energy offsets are key to this as incineration was assumed to produce electricity and heat which offsets mostly fossil based sources. Many incinerators do not use the heat and the electricity benefits are reduced with the increase in renewable technologies—both these factors are region and time specific and can have a large effect on the results.

The JRC, for their five LCA case studies[169], assumed that 90% of the carbon in biodegradable plastics is released as carbon dioxide during composting—this is based on the threshold testing under EN 13432, but the likelihood is that this is much lower in practice (50-70%) with the remainder converted to biomass. The assumptions used for anaerobic digestion are more complex. The JRC calculated, for biodegradable beverage bottles, 35% of the carbon is released and of that 63% is methane and 37% is CO_2 under the assumption that the material partly biodegrades in AD and then continues this in a secondary composting stage. For both these systems, bio-based compostable plastic is likely to perform better in GHG terms compared with fossil based versions as the carbon released is short-cycle and considered to be close to neutral.

Conventional plastics do not have either of these end of life options and if they do end up in composting there are known detrimental effects, however these are yet to be quantified. No LCA studies have yet included scenarios where the conventional plastic is mismanaged into organic waste, despite this being known to be a problem in reality.

[168] Rossi, V. C.-E., Dubois, C., Humbert, S., & Jolliet, O. (2015). Life cycle assessment of end-of-life options for two biodegradable packaging materials: sound application of the European waste hierarchy. Journal of cleaner production.

[169] Nessi, S., Bulgheroni, C., Konti, A., Sinkko, T., Tonino, D., & Pant, R. (2018). Environmental sustainability assessment comparing through the means of lifecycle assessment thepotential environmental impacts of the use ofalternative feedstock (biomass, recycled plastics,CO2) for plastic articles in comparison to usingcurrent feedstock. The European Commission - Joint Research Centre (JRC).

Table 9: End of Life Scenarios for Different Plastic Types

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

Material	Landfill	Incineration	Composting	Anaerobic Digestion
Bio-based Compostable	Mixed evidence, but likely to release at least a small amount of methane	Releases **biogenic** CO_2; offsets energy generation	Releases **biogenic** CO_2; ~1/3 is converted to biomass	Mass released as ~1/4 mostly methane which is captured and offsets energy generation; ~1/3 is converted to biomass, the remining is **biogenic** CO_2[1]
Fossil-based Compostable		Releases **fossil** CO_2; offsets energy generation	Releases **fossil** CO_2 ~1/3 is converted to biomass	Mass released as ~1/4% mostly methane which is captured and offsets energy generation; ~1/3 is converted to biomass, the remining is **fossil** CO_2[1]
Bio-based Conventional	Inert	Releases biogenic CO_2	Unwanted contamination but inert – not viable waste disposal route	Unwanted contamination but inert – not viable waste disposal route
Fossil-based Conventional		Releases fossil CO_2		

1. It is unclear exactly which proportions are converted to methane, CO_2 or biomass. This will largely depend on the resident time and whether there is a subsequent composting stage – the latter is assumed in this instance as described in the JRC feedstock LCA report.

Source: Adapted from JRC (2018)

6.2.5 Key Conclusions

Key Conclusions – Environmental performance of compostable plastics from an LCA perspective

Results from LCA studies reviewing or conducting comparative LCAs on compostable plastics and conventional fossil-based plastic mostly agree that in some impact categories the bio-based compostable plastic has lower impacts and vice versa in other impact categories, but the results are highly dependent upon system boundaries, scope, data limitations and critical assumptions, such as feedstock, end of life treatment and biodegradation.

The main take away points from two comprehensive EU studies are:

- Generally, studies are inconclusive and often have conflicting results. Methodologies for assessing the end of life for compostable plastics and the production impacts of bio-based plastics require further development to enable accurate and fair comparisons.

- The biological treatments of compostable products do not offer general benefits compared to recycling or incineration. Both studies emphasize that landfilling of compostable plastics should be avoided in order to reduce climate change impacts.
- Compared to production the EoL stage often has low contribution to the overall impacts.
- Bio-based, compostable products can offer benefits in some impact categories, especially climate change but show higher impacts in other categories compared to fossil-based plastics considering an average EU EoL.
- Generally, throughout the LCAs case studies the life cycle phase contributing to the majority of impacts was the production stage.
- The important factors influencing the environmental performance are feedstock and energy use during production.
- The studies highlight several limitations that alter a full comparison between the compostable and the fossil counterparts due to limitations on data on compostable products.

7.0 Criteria Setting

This section of the report brings together the knowledge of previous sections to assess the possible conditions in which the use of compostable products and packaging could be beneficial. Criteria are derived against which specific applications can be tested.

7.1 Methodology

The methodology for developing the criteria has been twofold:

- Requesting and collecting stakeholder position statements and deriving key criteria from the statements; and,
- After deriving an initial long list, discussing the refining this list during and after a stakeholder meeting.

The full list is shown in Appendix A.4.0 together with which position statements were used to derive the criteria.

7.2 Proposed Prerequisites

From the stakeholder engagement process and the preceding research, it has become clear that it is appropriate to define the prerequisites that need to be achieved for the disposal of compostable packaging alongside biowaste to be considered an option.

This is in order to make sure that;

1) The organic waste treatment infrastructure is capable of dealing with these materials/products with no negative effects.
2) The material/product performs as expected in industrial composting; and,
3) The waste treatment method and the appropriate disposal actions required by the end user to facilitate this is effectively communicated.

Without these three elements above in place, the likelihood of negative consequences is high i.e. consumer confusion leading to improper disposal and/or situations where organic waste treatment is hampered. Table 10 describes the proposal for these prerequisites.

Table 10: Proposed prerequisites for packaging and products where primary disposal is through composting or anaerobic digestion

	Prerequisite
1)Waste Treatment	1) Separate collection of organic waste is in place.
	2) Aerobic composting must be given sufficient time that biodegradation can fully occur and anaerobic digestion must include an aerobic composting phase. This must not result in negative financial, operational or environmental consequences.
2)Product Specification	3) Products in their entirety must meet EN Standards for composting of packaging or plastic products – i.e. compostable products should not be comprised of components that do not meet the standards
3)Communication	4) The term 'biodegradable' is not used on the product or any marketing communication associated with it.
	5) The correct waste management route is clearly identifiable for the end consumer/user and this is communicated effectively on the product/ packaging

7.3 Recommendations for Communication

The word 'biodegradable' in the context of compostable plastics is considered by the majority of stakeholders to be an unhelpful term when used in marketing claims and that at best is confusing and at worst can lead to unwanted behaviour such as littering. It is clear that precision in the use of terminology will help with communication and therefore it is important to use terminology on the product that only relates directly to the preferred waste management practice. This is why it is recommended that the term biodegradable is not used to

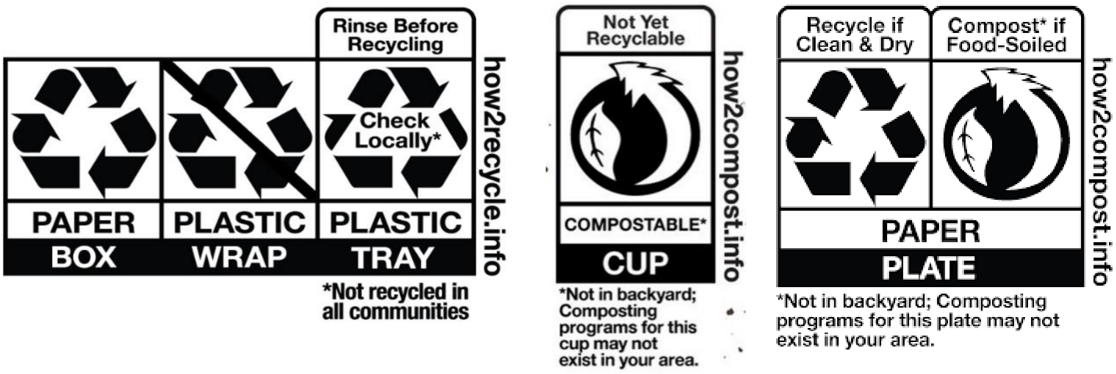
Although labelling and communication in itself is not likely to remove all chance of negative consequences from some products being made from compostable plastic (i.e. confusion leading to more plastic contamination in composting), looking at ways to communicate more effectively will be important.

Currently there are no standardised ways of communicating the correct way for consumers to recycle packaging across Europe—largely due to the different ways in which systems operate. The same goes for communication for compostable plastics, where currently the messaging is often at the discretion of the producer who may also chose to display one of the labels from certification schemes such as TUA Austria or Din Certco. Neither label helps direct the consumer towards a disposal method—understandable as the labels are used across Europe.

One example from the USA that is worth highlighting is the How2Recyle label which introduced a How2Compost label in 2016. Figure 18 shows examples of these labels with the original recycling label on the left and two examples of the composting label – importantly it also allows for other non-plastic materials to be designated compostable if the circumstance dictate. There are three important aspects to this labelling system that could be considered good practice:

- The composting labelling is consistent with the recycling labelling and therefore is a recognised system the consumers look for on packaging.
- The label is linked directly with the certification process – in the US this is the BPI[170] who certify products to the US equivalent of EN 13432.
- The website (using the web address on the label) can be used to search whether the local waste collection accepts the materials – although the scope of this service appears limited in functionality and integration at present.

Figure 18: The USA 'How2Recyle/compost' Logos



These three aspects could be incorporated into the basis for labelling schemes in the EU with the expectation that the execution may be different between different Member States. A possible Member State that this could be trialled in is France as the recent legislation is likely to lead to a large increase in the use of compostable bags. Under France's Roadmap for the Circular Economy[171], a key target is to simplify waste sorting processes by having unambiguous sorting instructions and harmonizing the colours of waste bins throughout the country (Figure 19) and therefore incorporating a compostable label at an early stage would help with consumer recognition and acceptance—this may be particularly important given the relatively low level of separate organic waste collection in France.

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170 https://bpiworld.org/

171 Roadmap for the circular Economy - 50 measures for a 100% circular economy, Ministry for an Ecological and Solidary Transition and Ministry for the Economy and Finance. Last accessed 19/02/19 https://www.ecologique-solidaire.gouv.fr/sites/default/files/FREC%20anglais.pdf

Figure 19: CITEO Sorting Labelling

Translation: Think about sorting! – Tray and plastic film to dispose – Carboard box to recycle

7.4 Recommendations for Waste Treatment

By 2024, separate collection of bio-waste is set to become mandatory in the EU as part of revisions Article 22 of the Waste Framework Directive.[172] Until then, this practice should be expected to still vary between and within Member States. Without separate collection in place there is no reliable and consistent way of making sure that compostable plastics reach appropriate composting facilities rather than ending up in residual waste.

The current *disintegration* time specified in EN 13432 is 12 weeks (5 weeks for AD). Evidence suggest that this timescale is not always reflected in reality (the product of 'fresh compost' in Germany for example). Adapting timescales to suite the use of compostable plastics is likely to be unfeasible at present. Equally, setting a minimum of 12 weeks may also be unhelpful when some modern and highly controlled processes can take less time.

The wording of the proposed prerequisites in this study does not specifically point to a time period but that the process "must be given ***sufficient time*** that biodegradation can fully occur." This time period may differ between countries, but the important aspect is that products certified to EN 13432/14995 will be treated effectively in the process. The only way to test this is to sample and catalogue the outputs of the composting process—an activity that has been undertaken for many years in Italy. If the minimum composting standards in a country have been demonstrated to effectively compost compostable plastics there will be opportunities to promote the use of the material in certain applications, if this is not the case, the material should not be promoted.

[172] Directive (EU) 2018/851 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.150.01.0109.01.ENG

7.5 Proposed Criteria for Beneficial Use

Table 11 shows the proposed criteria for identifying potentially beneficial uses of compostable plastic. These centre around two key headline criteria:

1) there should be environmental benefits to using compostable plastics over alternatives – this leads to several sub-criteria that relate to the means or the conditions in which such benefits could be realised.
2) there should be no (direct or indirect) reduction in the quality of the compost — this relates to compost quality, but goes beyond the proposed prerequisites for the material itself to focus on the wider consequences. This is supported with two sub criteria identifying scenarios where non-compostable plastic contamination is not increased or is even reduced.

A weighting is applied to these sub-criteria in order to recognise that some aspects are more important than others – in this regard it is considered that preventing an increase in non-compostable plastic contamination is the most important. Secondary to this is a net reduction of contamination along with the other environmental benefits gained from increasing biowaste capture. Criterion 1c allows for LCA to be used as a tool to prove environmental benefits, but is not a definitive criterion. Finally, criterion 1a has the lowest weighting in recognition that there may be circumstances where other benefits may outweigh those gained from recycling or reuse. The current pledge under the EU plastics strategy is to ensure that all plastic packaging is recyclable by 2030. This means that this criterion should have less importance over the coming years and that beneficial applications of compostable plastics will be most effective where 'co-benefits' can be achieved (i.e. in a situation where *all* packaging is 'recyclable').

The criteria rejected for inclusion at this point as detailed in Appendix A.4.0, however it is important to directly address one specific criterion that has been suggested primarily by the compostable plastics industry, namely for situations where the product is contaminated with food waste. In this regard it is important to make the distinction between food *waste* and food *residue*. The latter is small amounts of food (primarily liquids) that remain on the packaging and after use and, in this particular application, would be considered unavoidable. Where this might be considered as *waste* is when food that could have been consumed, remains. It is clear that this should be tackled through waste prevention measures and is not a reason to use compostable materials. The claimed benefit is often that the food waste/residue can be recovered if the packaging is compostable and set to organic treatment. Whilst this is true, the benefit associated with a relatively small amount of unavoidable residue is likely to be negligible and not a sufficient reason in itself. The most likely relationship with food is that it increases the likelihood of the packaging ending up in organic waste and therefore if this is compostable it will reduce plastic contamination.

One aspect of compostable plastics which is often discussed is the economic benefit of this material in compost compared with the equivalent plastics in recycling. It is implicit in the above criteria that on a purely material basis, recycling has the higher value. This is where identifying the specific applications is important, as there will be some where the material value is less relevant than the added value e.g. increasing food waste capture.

Table 11: Proposed Criteria for Identifying Applications for Which Design for Composting May Be of Added Value

	Criteria	Wtg
1	**The use of compostable plastic brings 'environmental benefits' over alternative materials**	
1a	This application could not have been designed for reuse or recycling/would not undergo material recycling if designed for recycling	3
1b	The use of compostable plastic for this specific application can be expected to significantly increase the capture of bio-waste compared to non-compostable alternatives	4
1c	Through the use of LCA or similar environmental assessment tool it can be demonstrated that compostable plastic is the preferred material for this particular application	3
2	**The use of compostable plastic does not directly or indirectly result in a reduction of the quality of the resulting compost**	
2a	The use of compostable plastic for this application does not lead to consumer confusion and subsequent increasing contamination with non-compostable plastics.[1]	5
2b	The use of compostable plastic for this application can be expected to significantly reduce the contamination of compost with non-compostable plastics (from this application) compared with current practice	4

Notes:

1. It is possible to require the whole product group to be designed for composting to avoid the coexistence of compostable with non-compostable materials within the same application.

7.6 Criteria Testing

Table 12 shows the ten most common applications that were identified in the market analysis in Section 3.3.2. It should be noted that single use cutlery is due to be banned across the EU under the SUP Directive and compostable plastics are not exempt from this—these items are therefore no tested against the criteria. Some of the applications represent groups of products and therefore to test the criteria, specific examples within these product groups have been chosen.

Table 12: Application Examples

Application	Example
Carrier bags	Carrier bags used in supermarkets
Biowaste bags	Biowaste bags as liners for indoor caddy
Other flexible packaging (food and non-food)	Clothing bags e.g for shirts
	Pre-packed fresh fruit bags for e.g. apples/bananas
Single use trays	Trays used for fast food
Rigid packaging (food and non-food)	Rigid fast food Containers
Single use cups	Single use paper cups with plastic liner
Bags for loose products (vegetables and other)	Supermarket vegetable bags
Coffee pads, filters and capsules	Coffee capsules/pods

As well as key products identified in the market assessment, products that are considered to be benchmarks at either end of the spectrum (i.e. detrimental>>>beneficial) are also tested; the single use bottle is a product that is universally considered by the stakeholders engaged for this study to be an example of a packaging product that should not be made from compostable plastic. At the other end of the scale, tea bags and fruit labels are considered by the compostable plastics industry to be archetypal examples of beneficial use. Two further scenarios are also added;

- trays used for fast food in a ‘closed system’ (i.e. a canteen where all products are compostable and are all collected in special bins to be sent to a composter) where reuse is and is not possible; and,
- a situation where non- compostable coffee pods are banned.

These are included to demonstrate that the same product may or may not be beneficial depending upon the specific circumstances.

Table 13 shows the results of the criteria testing. Each of the products are rated 1-5 against the criteria. A rating of five considers the criterion statement to be completely true whereas a rating of one is considered completely untrue. A rating of three means the evidence is mixed or unconfirmed. The benchmarks performed as expected with both tea bags[173] and fruit labels highlighted as having potential for added value when designed for composting – in large part due to the fact that they are never recycled and will regularly end up in biowaste (with the conventional plastic elements becoming contamination). Conversely, the single use bottle fails in all of the criteria and therefore does not represent a beneficial use example. This does not discount the use of alternative materials to PET for use in bottles such as PLA, but they should not be marketed as compostable. PLA is a special case where it can be composted, but also there is evidence of mechanical recycling taking place in one isolated case in Belgium (but this is far from widespread or likely to be) – it is clear that both of these waste management routes cannot exist in parallel for the same products (especially when they look identical) as this can lead to confusion. If PLA is used as an alternative to PET it should not be for its compostability.

The other example products are also situation specific in some instances – the assumptions for these are outlined below the table. For example, the carrier bag is assumed to be reused as a caddy liner some of the time. If this was not the case, the increase in capture of biowaste would be given a lower score and LCA studies (Section 6.1) generally do not show that this material—compared with conventional plastic— is the best option unless reuse is part of the lifecycle. Similarly, it is assumed that both compostable and non-compostable versions of carrier and vegetable bags will exist on the market and therefore confusion and contamination issues could result. **The results of this criteria testing example would therefore change depending upon the scenario and therefore cannot be universally applied or conclusions drawn that are true in every circumstance.**

A further example of this is for trays used for fast food. Whether it is beneficial to make the product out of compostable plastic entirely depends upon the circumstances. The three examples given here are; a situation where the packaging ends up in litter bins and likely residual waste; a close system where reuse is not possible (likely to be niche circumstances) and; a closed system where reuse is possible i.e. a canteen with washing facilities. Only the closed system where reuse is not possible is likely to be a beneficial application for compostable plastic for this product. Where reuse is available, there are no benefits in terms of the criteria being tested against.

Fast food tubs also do not appear to be a beneficial use of compostable plastic and this is likely to be reflected in other rigid fast food applications as well. The same is also true of single use paper cups with a plastic liner; both do not help with capturing biowaste, but also may be confusing for consumers and lead to more contamination in composting for the same reasons as the single use bottle—most likely these items will end up in litter bins where they are unlikely to be composted.

[173] Referring to paper teabags that are often heat sealed with polypropylene and therefore contain plastic that is not obvious, rather than bags that are entirely polymer based.

Biowaste bags and vegetable bags appear to be the most beneficial applications for compostable plastic films when the latter is reused as biowaste bag, however the relationship between these two products is important and certain local or national policies will affect this. For example, if biowaste bags are provided for free to encourage collections, the vegetable bags are less likely to be reused and the benefit is lessened. On the contrary, if biowaste bags are mandatory, but not provided, the vegetable bag may be more beneficial as its reuse is almost guaranteed.

Coffee capsules provide the most benefit in a situation where alternatives are banned—this would reduce consumer confusion and capture the coffee biowaste. Several of the other applications sit in the middle ground where the benefits may be improved or worsened depending upon the circumstances, but should not be particularly promoted at this time.

Figure 20 shows the products on a continuum using the weighted % of maximum scores (i.e. 0-100%) in order to visually compare the results. This is based on the general assumptions identified in Table 13 and therefore it may look different for each Member State depending upon whether these assumptions hold true (or other considerations come into play). The cut-off point between which applications are promoted and which are discouraged is also a decision process that should be taken at the Member State level especially for those items which fall into the grey area in the middle (i.e. neither detrimental nor beneficial).

It should also be recognised that not all of these applications are likely to be covered under the Packaging and Packaging Waste Directive primarily due to the Article 3(1)i that states that an item should not be considered as packaging if it *"is an integral part of a product and it is necessary to contain, support or preserve that product throughout its lifetime."* Products such as coffee pods and teabags are likely to be described by this clause and therefore the mechanisms for promotion or restriction of these items or similar may be different.

Figure 20: Compostable Plastics Beneficial Use Continuum

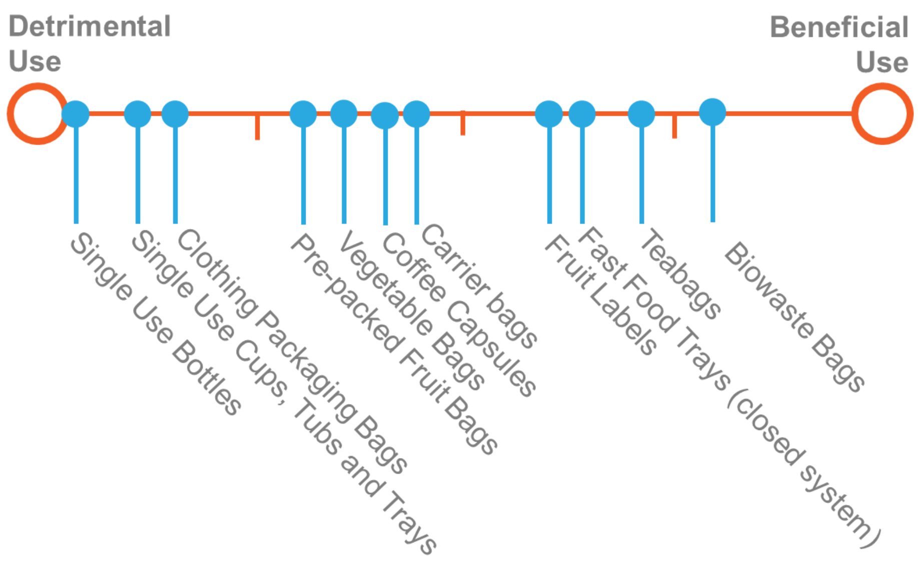

Table 13: Criteria Testing (5= completely true, 1= completely untrue, lowest weighted score possible = 19, highest = 95)

Example products	Not recyclable or could not have been designed for reuse	Increases the capture of bio-waste	LCA demonstrates preferred option is compostable plastic	Reduces the contamination of compost with non-compostable plastics	Does not lead to increasing contamination	Wtd Score	% of Max Score
Weighting>>	**3**	**4**	**3**	**4**	**5**		
Carrier bags used in supermarkets[1]	2	3	3	2	3	50	41%
Biowaste bags as liners for indoor caddy[2]	5	5	3	4	4	80	80%
Clothing packaging bags e.g. for shirts	2	1	2	1	2	30	14%
Pre-packed fresh fruit bags	4	2	1	2	2	41	29%
Trays used for fast food[3]	2	1	1	1	2	27	11%
Fast food Trays (closed system - reuse unavailable)[4]	4	5	3	3	3	68	64%
Fast food Trays (closed system – reuse available)	1	1	1	2	2	28	12%
Rigid Fast food Containers[3]	2	1	1	1	2	27	11%
Single use paper cups with plastic liner[5]	2	1	1	1	2	27	11%
Supermarket vegetable bags[6]	2	3	3	2	2	45	34%
Coffee capsules/pods[7]	2	5	3	1	2	49	39%
Coffee capsules/pods (alternatives banned)	2	5	3	3	5	72	70%
Benchmarks							
Single Use Bottle	1	1	1	1	1	19	0%
Fruit Labels	5	1	2	5	4	65	61%
Tea Bags (plastic heat sealed)	5	2	3	5	4	72	70%

Notes:

2. Carrier bags - Assumes that carrier bags are sometimes used as a caddy liner and that conventional carrier bags are currently a significant source of contamination in biowaste. There are also conventional bags on the market at the same time which can cause confusion.
3. Biowaste bags - Assumes biowaste bags are provided for free by municipality
4. Fast food trays and containers - Assumed that these end up mostly in residual waste, not composted
5. Fast food trays used in closed system – All waste is collected and composted together. Only in niche applications where no reuse is possible
6. 'Single use' is specified as these are still on the market and reusable alternatives may not always be practical
7. Supermarket vegetable bags - Assumes that bags are sometimes used as a caddy liner and that conventional bags are currently a significant source of contamination in biowaste. There are also conventional bags on the market at the same time which can cause confusion.
8. Coffee capsules/pods - Assumes both compostable and non-compostable pods on the market with the potential to confuse consumers

8.0 Compostable Plastics in Home Composting

Home composting as a means of treating domestically produced biowaste is an attractive option because it eliminates collection and transport costs of the waste, it offers a means of improving soil quality without the need for chemicals, and also encourages local responsibility for waste. However, it has drawbacks when viewed solely as a potential means of waste treatment, mostly because it is difficult to monitor the quantity of waste being treated, as well as the quality of the output.

This section of the report seeks to assess the feasibility of establishing criteria for labelling plastics as home-compostable for treatment in home composting situations. It identifies the conditions to be found in different types of home composting systems used across the EU and comparing them with the criteria set in existing standards.

The following themes are covered:

- Systems and practices of home composting
- Conditions in home composting affecting biodegradation of plastics
- Comparison of compost advice, promotion and practice across six EU countries
- Standards and Certifications for Home Composting
- Comparison between frameworks and actual home composting conditions

Based on this analysis a set of recommendations are formulated for approaches to address the discrepancies between existing frameworks and conditions to be found in practice. These have relevance for any forthcoming EU standards and communication towards home composters.

8.1 Systems and Practices of Home Composting

Composting is an age-old practice that is more akin to baking a cake rather than building a Lego model. Many different recipes exist, containers come in all shapes and sizes, and cultures vary on key ingredients, but with a careful selection and right mixing the end product is recognisably similar – a nutrient-rich, dark brown compost that can be used beneficially to improve soil condition and plant growth.

The active process in composting is the action of microbes, bacteria and fungi that breakdown organic material. When looking at compost systems and practices the best results are found when the ideal conditions are created for the microbial inhabitants. They thrive in a dark, warm environment that is humid but not too wet, and with sufficient access to oxygen. In designing a compost system these requirements are balanced with certain practical factors; the ease of adding organic matter, the removal of leachate and the ease of unloading the compost.

8.1.1 System Design – Containers for Home Composting

There are a wide variety of containers on the market for those interested in home composting, and home-made containers can function equally as well as commercially available items (see Figure 21).

Figure 21: Range of compost containers for purchase of home construction

Compost containers should be situated in a shady location, not in direct sunlight or they risk drying out. Ideally, a container is raised slightly to allow leachate to drain away and allow air to circulate, though they can be placed directly onto earth.

Open systems are exposed to the elements and the material can be held within a slatted container or piled up in a heap. Closed systems use a container with a lid to reduce exposure to the elements and ventilation of the compost is achieved through holes or louvres. It can be slightly more difficult to control moisture levels in an open system, but it's still a popular choice amongst gardeners; one study of composting in France reports that 64% of households that compost at home, use an open pile system.[174]

The size of the container affects the biological process; a pile that is too small may not facilitate a build-up of temperature and hence support microbial action. It will also lose

[174] Olivier, Stephane, Royne, Veronique, and Rebert, Mylene (2009) *Enquête nationale sur la gestion domestique des déchets organiques*, 2009

heat more quickly slowing down the process. A larger pile may hold too much water, thus inhibiting air flow. A minimum size of 200 litres is recommended to achieve a temperature increase needed for the composting process.[175] While smaller bins are available, they may require the use of additives to kick start the composting process. A variety of 'compost starter' products are available containing a mix of nitrogen and microbes, though there is considerable debate as to their efficacy. Tumbling composters are also typically smaller than 200L to allow for the turning of the bin. This mechanical action aerates and mixes the compost with the aim of accelerating the composting process.

In colder climatic conditions an insulated container is required to keep the compost warm enough to facilitate microbial activity. Until 2019 Finland only permitted home composting in closed and insulated containers, and containers on the market in Finland typically have a thermometer built in (see Figure 22). Similarly, in Sweden, to be acceptable the system needs to be insulated, vermin proof and have ventilation holes covered with nets[176]. These products are more costly than standard compost bins, perhaps limiting the number of households for whom this is a viable option.

Figure 22: Compost containers for cold climates

In the warmer climates of Southern Europe too much aeration of a compost pile will result in the compost drying out and watering the compost is more common practice.

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[175] *Compost Systems*, accessed 27 June 2019, http://www.homecompostingmadeeasy.com/compostsystems.html

[176] Ermolaev, E., Sundberg, C., Pell, M., and Jönsson, H. (2014) Greenhouse gas emissions from home composting in practice, *Bioresource Technology*, Vol.151, pp.174–182

Recommendations in Greece suggest lining the compost container with cardboard to help retain moisture.[177] Sometimes composters also use holes in the ground to keep the compost cooler.

8.1.1.1 Multi Container Method and Community Composting

Many composting manuals suggest that best results can be obtained by having more than one composting pile, which allows the user to build up a good mix of constituents in a pile and then leave it with periodic turning, whilst slowly building up a new pile. This requires more space than single unit composting but can be done in a community composting setting where several households combine their waste in one location.

In many European cities, where apartment living is common and households do not have their own garden, community composting sites are used (see Figure 23). These range in size from multi-household bins serving around 5 households, to community composting sites that serve 50-80 households. In Basel, where composting has been promoted since 1987, 30 such larger sites exist.[178]

Where community compost schemes are in operation they rely on a 'compost master' who is trained to care for the system and takes on the role either as a volunteer or as a paid employee of the scheme. This reduces the need for each individual householder to understand the composting process. Householders can simply bring their waste to the site, often at allotted times when the site is being attended, and the community composter regulates the balance of bulking material to household waste. Multi-household composting increases the load size and frequency of loading which will positively affect the efficiency of the biodegradability process [179].

[177] Mediterranean Garden Society, Greece *Compost and how to make it*, accessed 8 July 2019, http://www.mediterraneangardensociety.org/compost.html

[178] *FICHE 4 : BALE (SUISSE) - PDF*, accessed 9 July 2019, https://docplayer.fr/18727475-Fiche-4-bale-suisse.html

[179] Andersen, J., Boldrin, A., Christensen, T., and Scheutz, C. (2010) Greenhouse Gas Emissions from Home Compoosting of Organic Household Waste, *Waste Management*, Vol.30, pp.2475–2482

Figure 23: Community composting (Navarre, Spain, Paris and Digne les Bains, France)

8.1.1.2 Indoor Composting

In an urban setting where space is limited, indoor composting is also a viable solution for households, though households without a garden are likely to have less need for making their own compost. There are two ways of composting indoors. Vermicomposting (worm composting) can be done in containers as small as 50L, because the biological process is markedly different from outdoor home composting. Red worms digest household food waste and excrete worm castings which are rich in minerals useful for plant growth. This process can be done within three to six months. Another method for indoor composting called Bokashi was developed in Japan in the 1980's and uses a bran inoculated with microbes to ferment kitchen waste in anaerobic conditions, usually a special container that allows the waste to be tightly covered. The leachate of this process is beneficial to plants.[180] It is unlikely that either of these processes will be able to biodegrade plastics as we do not know if worms cannot directly consume plastic materials or if the fermentation process will breakdown these materials. This could lead to consumer

[180] *Bokashi: All You Need to Know*, accessed 8 July 2019, //www.planetnatural.com/composting-101/indoor-composting/bokashi-composting/

confusion when labelling products as 'home compostable' as increasingly these practices are known as composting.

8.1.2 Effective Management of the Compost Pile

Although there are a wide variety of composting systems that a home composter can use the more significant factor affecting the compost outcome is how the compost is managed as an active process.

Managing the compost pile comprises the following activities:

1) Careful selection of the materials
2) Initial construction of the pile
3) Addition of further materials
4) Regulation of moisture levels
5) Regular mixing the pile

Variations in how composting is practiced can be found in the materials fed into the compost (whether meat and fish are included, or what type of bulking material is available locally), how often the compost is added to and turned. These variations in practice all affect the composting process by creating different biotic conditions which allow the microbial population to thrive. The key abiotic conditions are temperature, moisture levels, oxygen availability, pH and carbon/nitrogen balance. In general, what is added to the pile is key to affecting the moisture levels and carbon/nitrogen balance, while how often the pile is added to and turned affects the build-up of temperature.

8.1.2.1 Materials to Include

Compost specialists refer to two types of organic waste; 'green' waste – most commonly food waste and grass clippings, and 'brown' waste – commonly woody garden material such as woodchips, leaves or pine needles or shredded paper/cardboard. Table 14 shows the different C/N ratios of common composting materials. This simple distinction is important because green waste is high in nitrogen and moisture, while brown waste is higher in carbon and provides structure within the compost helping the flow of oxygen, which bacteria need to function. Brown waste is also referred to as a 'bulking agent'. The ratio of bulking agent to food and other 'green' waste is crucial to the composting process. An example of an ideal balance would be for every kg of food waste around 0.25 kg of dry leaves are added to the compost. However, managing the inputs based on this sort of scientific approach is far beyond what would be expected of the average home composter (and most want to compost what they have available, not search for additional correct materials). Because of this, advice generally ranges anywhere from a 2:1 brown:green ratio by volume to a 1:1 or even 1:2.

Table 14: Examples of Nitrogen and Carbon Rich Compost Feed

Nitrogen Rich 'Greens'	Carbon Rich 'Browns'

Input	C:N Ratio	Input	C:N Ratio
Plants/leaves	10-20:1	Card and paper	150-200:1
Coffee grounds	25:1	Fats and oils	250:1
Food Waste – fruit	16:1	Hay and straw	90:1
Food Waste- vegetables	10-15:1	Autumn fall or evergreen leaves	60-80:1
Grass clippings	10-15:1	Wood branches/trigs	700:1
Manure	20-30:1	Sawdust	500:1

Source: Jane Gilbert, The composting Trouble-shooter

8.1.2.2 Ongoing Management of the Pile

While it is not easy for a home composter to directly monitor the carbon nitrogen balance in their pile, moisture levels are a good proxy for this. Adding too many 'greens' which can occur if food waste is not balanced with bulking agent, will lead to an over-moist pile. The moisture can be monitored using the simple 'squeeze test' taking a handful of compost and squeezing it to see if water drips off, aiming for the moisture level of a damp, wrung out sponge. Indeed, monitoring moisture levels is one of the main ways that a home composter can judge the overall functioning of their compost pile as it is easier to monitor and change than temperature.

Moisture levels can be adjusted by changing the ratio of bulking agent to food waste or watering the compost. In warm climatic conditions the moisture levels will need regulating with the addition of water, sometimes daily, so the compost pile should be sited near to a water point. In this way differences in climatic conditions can be adapted to, and in both dry and wet climates active management of the compost is needed.

In the colder climatic conditions of Northern Europe, the ambient temperature is suited to composting for a much shorter time of the year than in continental Europe. This window can be extended through careful management of the compost pile the compost process can be kept active by insulating the compost container and continuing to add more waste and turn it regularly. However, if the wet compost freezes the composting process simply pauses and resumes when the air warms up again. [181]

Given the extra management needed to maintain active compost in colder climates it is likely that the numbers of people committing to do this are small. Similarly, in Mediterranean Europe the dryness of the summer months will inhibit the composting process and in order to sustain this regular watering of the pile is needed. It is likely that

[181] Meillakotona (2019) *Komposti – ammattilaisten vinkit käyttöön ja hoitoon*, accessed 28 October 2019, https://www.meillakotona.fi/artikkelit/ammattilaisen-ohjeet-kompostin-hoito

the numbers of people producing successful compost year-round in these climates is much lower than in Atlantic/Central/Eastern Europe.

Sufficient aeration can be achieved by choosing a well-ventilated container, and managed with regular turning of the compost pile. Turning the compost improves the airflow and has been shown to increase the temperature, so facilitates the build-up of high temperatures which can produce compost in just a few months.

Even with good management different natural materials will vary in how long it takes them to compost. Table 15 shows some examples of the different length of time needed for natural rotting of different materials. Some of these materials can be shredded to speed up the time, others are chosen as bulking agents precisely because they rot more slowly so maintain the structure in the compost pile. An experienced home composter will not be surprised to find some materials remain intact even when the surrounding material has turned into useable compost.

Materials that would require a full year to biodegrade in an ambient climate may require two annual cycles or more in colder climates —this will be the same for the organic matter and biodegradable plastics so that although the process is longer than typical it is unlikely that the householder will be presented with perfect compost but with the plastics still intact.

Table 15: Typical compost times for different waste materials

Typical time to rot down	Examples of waste materials
within 6 months	Kitchen food waste, grass, vegetable plants such as carrot tops, dead flower heads
1-2 years	Flower stems, hedge clippings (but not evergreens) shredded woody prunings, autumn leaves
3 years or more	Wood shavings, evergreen leaves or conifer needles, egg shells, oak and beech leaves, avocado stones, cabbage stems

Source : Allan, D. (2019) The Home Composter*, accessed 29 October 2019,*
http://www.askorganic.co.uk/composting/How%20long%20to%20make%20compost.htm

8.1.3 Defining Best Practice in Compost Management

Batch composting is a term used for an efficient composting process that can produce useable compost in several months in benign climates. Batch composting involves building a complete pile in one go, with a layering of green and brown material and a layer of soil can be included. The pile is kept moist and mixed weekly but no new material is added in this time. High temperatures can build up in this pile, supported by the regular mixing of material resulting in the fast production of compost.

A more common home composting practice is known as add-as-you-go composting which involves regular additions of small quantities of food waste, daily or weekly thereby suiting the waste management needs of a household. After an initial layer of 10-15 cm of soil and brown material, then kitchen waste can be added as it is produced, always being covered with another layer of brown material to create the right moisture balance. As with batch composting the pile should be mixed periodically and moisture levels checked.

The add-as-you-go composting style creates a compost system that is less likely to achieve very high temperatures so the decomposition of material is longer and slower than in batch composting, taking between 6-12 months to mature. Sometimes this is described as 'cold composting'. However, if managed well with careful balancing of inputs and regular turning, a well-managed add-as-you-go pile can be as successful as a batch pile.

In an attempt to define 'best practice' of home composting an artificial distinction can be drawn between a 'well-managed' pile and a 'basic' pile. This is different from the distinction between batch composting and add-as-you-go because an add-as-you-go pile can be well-managed and produce hot compost if done carefully. Both approaches can produce compost from home waste but a well-managed pile will reach significantly higher temperatures in its core, resulting in a faster composting process and one more likely to have the conditions needed biodegrade plastics. A basic pile will remain at lower temperatures and need a full year to compost organic materials. It is likely to have a lower potential to biodegrade plastics. These two methods are both successful at producing compost and should be viewed in contrast to the even more minimal practice of dumping organic waste and leaving it to rot. Waste dumping is not composting and it can be assumed that householders engaging in this practice also do not believe they are composting.

Table 16 shows the key differences between a well-managed pile and a basic pile. In 8.3.2 Abiotic Conditions in Home Composting, the range of conditions resulting from such practices is explored in greater detail.

Table 16: Features of a well-managed pile and a basic pile

	Well-managed pile **(batch or add-as-you-go)**	**Basic pile** **(add-as-you-go)**
System	Suitable container selected for the climate Ensures temp and air regulated for climate	Any container is used
Practices	Careful layering of different materials – bulky materials are shredded Ensures health C/N ratio 10-40 and aeration	Basic layering of materials

	Balance of 'greens' and 'browns' is monitored and adjusted Ensures health C/N ratio and aeration	Garden waste and food waste added in the quantities produced by the household
	Moisture levels are checked using squeeze test and adjusted Ensure moisture levels around 50%	Low awareness of moisture levels
	Regular turning of the pile Ensures sufficient aeration	Infrequent turning
Resulting conditions	Hot composting (temp can reach above 45°C)	Cold composting (temps remain under 45°C)
Timescale	~3-4 months	~12 months

Community composting systems demonstrate how an add-as-you-go method can also be well managed. Community systems use an add-as-you-go style of feeding which allows households to bring their waste on a regular basis when they need to dispose of it. However, because they are managed closely by trained individuals, and they also have space for several compost vessels they can create and manage several 'batch' piles whilst still accepting new waste. This can result in a 'hot composting' process producing compost within several months.

Without targeted primary research it is very difficult to ascertain what proportion of households that engage in composting are knowledgably managing their piles or adopting a basic practice. Arguably, the building or purchasing of a container signifies an investment that may lead the householder to be more engaged and proactive in managing the system, but this cannot be presumed. Furthermore, households that only adopt a more basic management practice are more likely to become discouraged, as the compost will take longer to become ready and be less appealing in form, potentially being too moist or slightly smelly.

8.1.4 Key Conclusions

Key Conclusions – Systems and Practices of Home Composting
Home composting can be successfully done in a range of ways but requires some knowledge and active management. The aim of managing a compost pile is to provide the ideal conditions for microbes (bacteria and fungi) to thrive. It is the microbes that drive the composting process by consuming carbon in the biowaste. **Best practice in compost management includes:** • Selecting a suitable container selected for the climate

    - Ensuring temperature and air regulated for climate
- Ensuring the balance of 'greens' and 'browns' is correct
    - C/N ratio is adequate for composting to take place efficiently
- Moisture levels are checked using squeeze test and adjusted
    - Ensuring moisture levels of around 50%
- Regular turning of the pile
    - Ensuring sufficient aeration and mix of C/N materials

Effective management of the compost pile:

It is possible to produce workable compost without following best practice by adopting a more basic practice; infrequent mixing, and infrequent monitoring of moisture levels. As long as the mix of materials is within an appropriate range and the compost pile is naturally aerated this will still produce compost but will result in low temperature composting process, remaining under 45°C and taking at least a year.

Though it is often recommended to build a compost pile in one go 'batch composting', a more common practice in home composting is 'add as you go' where fresh biowaste is added regularly. This latter suits the home composter's regular production of biowaste but is more likely to lead to a low temperature composting process.

Cold composting is very common in home composting, with temperatures remaining under 45°C and needing a full year for maturation. Hot composting is achievable with good management but it cannot be assumed to be the norm.

Without targeted primary research it is very difficult to ascertain what proportion of households that engage in composting are actively managing their piles according to this best practice or adopting a basic management practice. Arguably, the building or purchasing of a container signifies an investment that may lead the householder to be more engaged and proactive in managing the system (especially in Nordic countries where the initial investment is higher), but this cannot be presumed.

Other issues with system design

Composting in different climatic conditions is possible using adapted containers and careful management. Both colder climates and warmer ones require changes in practice to overcome the challenges.

Indoor composting methods such as vermicomposting and Bokashi are increasingly being promoted as solutions for urban residents who want to compost their waste. This presents an issue when labelling products as 'home compostable' as the biological process in these indoor solutions is unlikely to be able to biodegrade plastics which could lead to consumer confusion.

8.2 Comparing Home Composting Across Six EU Countries

There is little reported data on the extent and practices of home composting across different EU countries. This report seeks to build a picture of the situation in six Member States, informed from interviews and an analysis of publicly available information. The six countries are Belgium, France, Finland, Portugal, Spain and the UK. These were selected to present a range of maturity in biowaste management along with a range of climatic conditions.

8.2.1 Existing Biowaste Management

Biowaste forms a significant component of waste across the EU and is increasingly viewed as a commodity within the circular economy. Waste that is made from organic matter (putrescibles) comprises between 35-40% of Municipal Solid Waste (MSW). [182] Some countries, e.g. Switzerland, distinguish between biowaste and compost waste as not all putrescibles are suitable for composting.[183] It is estimated that the amount of compostable waste produced by a household in a year is around 45-55kg. [184] Biowaste can be transformed into valuable products using anaerobic digestion and industrial scale composting facilities and is also part of what is fed into a home composting system.

There is a patchwork of provision within countries and across the EU with regard to separate collection of biowaste. Even those countries that have made this a legal requirement are at very different stages in this process. For example, Lisbon is introducing a door to door collection of biowaste for the first time, starting in October 2019 with 6,700 homes covered. [185] Within the capitals of the countries compared biowaste capture rates vary from 0.2% to 42.7% indicating the different levels of maturity of the waste management systems. Table 17 summarises the biowaste capture rates for the six countries in this analysis.

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[182] EU Commission (2014) *Separate collection_Final Report.pdf*, accessed 22 August 2019, https://ec.europa.eu/environment/waste/studies/pdf/Separate%20collection_Final%20Report.pdf
[183] Piipo, S, and Pongracz, E (2014) Sustainable_bio-waste_strategy_in_Finlan.docx
[184] Andersen, J., Boldrin, A., Christensen, T., and Scheutz, C. (2010) Greenhouse Gas Emissions from Home Compoosting of Organic Household Waste, *Waste Management*, Vol.30, pp.2475–2482
[185] Portugal Resident (2019) *Councils to start 'composting' kitchen waste*

Table 17: Biowaste collection rates

Ctry	Is there a household collection of biowaste?	Biowaste capture rate in capital city (%)
BEL	Yes: Begun in Flanders in late 1990's	8.4
ESP	No – Bring points	No data
FIN	Yes, since late 1990's – but depends on population density Is a legal requirement in 108 of 450 municipalities	42.7
FRA	No, but started in Paris 2017	2.3
UK	39% of local authorities have a separate collection of food waste[186]	27.3
PRT	No, Pilot scheme starting in Lisbon in October 2019.	0.2

Source: EU Commission 2014[187]

Biowaste collection, when averaged across 28 EU capitals, is reported to be 19.6 kg/cap per annum, which is considerably less than the estimated potential diversion of biowaste from municipal collection into home composting - 150 kg/hhld/yr. [188] A successful community composting scheme in Galicia, Spain collects around 30kg/cap/yr. [189]

All this is likely to change throughout the EU at the end of 2023 when the Waste Framework Directive under Article 22(1)(a) mandates that Member States shall separately collect organic waste but also under Article 22(2)(b) shall 'encourage home composting'. How strongly Member States will provide this encouragement remains to be seen. Some existing home composters may begin to use the new biowaste collection, but those that compost to create a soil improver will likely not be influenced to do this.

A study in 2010 estimated that home and community composting could lower management costs of European countries by at least 34% and reduce greenhouse gas

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[186] WRAP (2019) *WRAP Dry recycling performance benchmarks*, accessed 28 October 2019, http://laportal.wrap.org.uk/Statistics.aspx

[187] Bio-waste collection rate provides an overview on the amount of bio-waste that is separately collected per inhabitant. This indicator allows the comparison between capitals since separate bio-waste collection is not yet well established across the EU. EU Commission (2014) *Separate collection_Final Report.pdf*, accessed 22 August 2019, https://ec.europa.eu/environment/waste/studies/pdf/Separate%20collection_Final%20Report.pdf

[188] Davey, A., Clist, S., and Godley, A. WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change., p.54

[189] Global Alliance for Incinerator Alternatives (2012) On-the-Road-to-Zero-Waste.pdf

emissions by 40% over current management practices. [190] However, home composting, when viewed solely as a potential means of waste treatment, has drawbacks mostly because it is difficult to monitor the quantity of waste being treated, as well as the quality of the output. Some argue that community composting offers a better means of waste management because it can be monitored more closely while offering the same ecological benefits as home composting.[191] Community composting also has limitations though as it requires a larger space, that is located close to households but at a suitable distance that residents are not affected by any possible odours. It also requires a suitably qualified or experienced person to take overall responsibility for management of the compost process and maintain the health of the compost. In some regions of Spain community composting sites are handling between 80-100% of biowaste. [192]

Other initiatives seek to fill the gap between industrial scale processing of biowaste and home composting by providing small scale decentralised solutions to biowaste management through micro-scale anaerobic digestion (AD) and solid-state fermentation (SSF) within the urban and peri-urban areas.[193,194]

8.2.2 Support for Home and Community Composting

Many Member States have been promoting home composting over the past 20 years though the current extent of home composting is difficult to ascertain as there is little incentive to monitor the practice beyond the impact of particular promotional schemes. Table 18 summarises the extent of data on home and community composting across these six countries.

Table 18: Data on the Extent of Home and Community Composting

Ctry	Extent of community composting	Extent of home composting
BEL	2,500 active 'master composters' in Flanders	34% of population
ESP	Intensive projects in a handful of areas. Some of these can treat 80-100% of the biowaste of the local community	unknown

[190] Adhikari, B.K., Trémier, A., Martinez, J., and Barrington, S. (2010) Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada, *Waste Management & Research*, Vol.28, No.11, pp.1039–1053
[191] Zero Waste Europe (2019) *Community Composting: A Practical Guide for Local Management of Biowaste Zero Waste Europe Guides/01*, 2019, https://zerowasteeurope.eu/wp-content/uploads/edd/2019/04/zero_waste_europe_fertile_auro_community_composting_guide_april_2019.pdf
[192] Plana, R. (2019) *Personal communication from Ramon Plana.docx*
[193] SCOW (2017) *Welcome to SCOW | SCOW*, accessed 30 August 2019, http://www.biowaste-scow.eu/
[194] Decisive 2020 (2019) *How innovative biowaste management can boost the circular economy*, accessed 30 August 2019, http://www.decisive2020.eu/events-item/how-innovative-biowaste-management-can-boost-the-local-circular-economy/

Ctry	Extent of community composting	Extent of home composting
FIN	Supported - Need to register their activity.	40% of households in Helsinki
FRA	Successful project in Paris since 2010 with 350 sites with waiting lists to join. 207,935 participants in the Paris scheme	35-43% of households with garden, 9-10% of apartments
UK	121 sites (20,500 tonnes/yr)	35% of households with a garden
PRT	5 sites in Lisbon in first year	900 participants in Lisbon project in first year

In order to register as a home composter some countries have certain requirements that must be met. For example, the German regulations specify that an applicant needs to have land of 25m^2, sufficient for the application of resulting compost, whilst in Sweden to be registered a household compost system needs to be insulated, vermin proof and ventilation holes covered with nets.[195] These registration requirements therefore offer a way of ensuring that the composting process is tailored to the practices required in a particular country. Some countries (e.g. Germany, Poland) have chosen to incentivise home composting by allowing self-declared 'home composters' to avoid paying waste collection fees as they will no longer be served by a biowaste collection service. However, this financial incentive has the potential to encourage self-declaration without adequately treating household bio waste.

8.2.2.1 Belgium

Promoting home composting has been part of the national strategy to reduce waste in Belgium since 1991. Tax levies were introduced to incentivise recycling and organic materials are one of the highest taxed items. Educational activities have been well supported, one example being the establishment of a 'compost masters' program in Flanders training citizens to volunteer to train others and manage community compost sites. In 2008 it was reported that there were 2,500 active master composters and 4000 citizens had been trained. From this it is estimated that in 2008 about 100,000 tonnes of organic materials were kept out of the waste collection system. By 2010, approximately 34% of the Flemish population—almost two million people—were composting at home.[196]

[195] Ermolaev, E., Sundberg, C., Pell, M., and Jönsson, H. (2014) Greenhouse gas emissions from home composting in practice, *Bioresource Technology*, Vol.151, pp.174–182
[196] Global Alliance for Incinerator Alternatives (2012) On-the-Road-to-Zero-Waste.pdf

8.2.2.2 Finland

Since 2016 there has been a prohibition on landfilling waste with more than 10% of organic material. It is reported that 40% of households in Helsinki compost their own waste. [197] Prior to 2019 all householders composting were required to register as home composters and had to use a thermally insulated container. The introduction of new waste management regulations in March 2019 dropped these requirements and instead only properties that are collectively composting with more than five apartments cooperating on this need to report this activity. Smaller households no longer need to register as home composters. [198]

8.2.2.3 France

A national study into the home treatment of organic waste in France found that 35 - 43% of households in a house (presumably with a garden) compost their kitchen waste, while only 9-10% of those living in collective housing (apartments) do so. [199]

Home composting is promoted nationally through an annual event 'tous au compost' run by the Reseau Compost Citoyen and supported by Ademe. Over 1000 educational events are organised each year including tours of local composting sites. [200]

An exemplar scheme in France is found at Besancon, where a local waste treatment company collaborated with the municipalities under an EU funded project 'Waste on a diet' from 2012 -2016. A 'pay as you throw' scheme for waste was introduced at the same time as supporting home composting and community composting. In 2016 70% of the population were either covered by a community composting site or had a composter at home. It is estimated that in 2016 over 50% of the population were treating their own biowaste by home composting and the decentralized composting facilities managed to divers 7436 tonnes of biowaste away from incineration. [201]

Despite being the most densely populated of Europe's cities, Paris has run a compost support program since 2010. Collective compost projects are approved if they have the support of at least ten participants and a suitable site. Training is then offered and over 350 sites have been established. Due to shortages of space these sites currently have waiting lists to join. [202] Current figures show 207,935 people in Paris are engaging in composting in their own biowaste.[203]

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[197] Piipo, S, and Pongracz, E (2014) Sustainable_bio-waste_strategy_in_Finlan.docx
[198] Helsinki Region Environmental Services Authority HSY *Waste management regulations | HSY*, accessed 3 July 2019, https://www.hsy.fi/en/residents/sorting/waste-management-regulations/Pages/default.aspx
[199] Olivier, Stephane, Royne, Veronique, and Rebert, Mylene (2009) *Enquête nationale sur la gestion domestique des déchets organiques*, 2009
[200] Reseau Compost Citoyen (2019) *Semaine nationale du compostage de proximité*, accessed 28 October 2019, https://www.semaineducompostage.fr/composter/communication
[201] Zero Waste Europe (2018) *The story of Besancon, case study 9*, 2018
[202] Paris to Go (2019) *How to Compost in Paris*
[203] Syctom (2019) *jecomposteenville.fr*, accessed 28 October 2019, https://www.jecomposteenville.fr/

8.2.2.4 Portugal

Launched in May 2018, the Lisbon City Council has begun the first program to support home composting in Portugal. Individuals can apply for a compost bin, but need to attend a day of training in order to receive their bin. By December 2018, 900 people had participated. In addition, the setting up of community compost sites is being supported with five currently in operation. [204]

8.2.2.5 Spain

Waste management in Spain is managed regionally with large variation in practices. Home and community composting is intensively supported in a few regions: [205]

- The province of Pontevedra (Galicia).
- Navarre.
- Basque Country.
- The province of Valencia.

In Hernani, Gipuzkoa, Basque country, the community composting system manages 80-100% of biowaste. There are 35 community composting units serving 700 households and a further 700 households are composting their own waste. The community compost scheme collects 30.8 tonnes a year, averaging 30kg per person per year. [206]

8.2.2.6 UK

Starting in 2003, the UK waste NGO WRAP has been working with local authorities to support the adoption of home composting through providing subsidised compost containers. By 2007 it was reported that 73% of local authorities were distributing subsidized bins and accompanying this with information campaigns. [207] More than 1,700,000 compost bins were supplied by WRAP up to 2007.

WRAP also reports that 35% of households with a garden compost at home. [208] This would indicate that around 8 million households compost. (Total number of UK households is 27.2 million, around 87% of which have a garden,[209] so, if 35% of these compost that is 8,282,400 households that compost – around 8 million).

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[204] lisboa a compostar (2018) *Câmara Municipal de Lisboa - Lisboa a Compostar | Compostores Comunitários*, accessed 2 July 2019, https://lisboaacompostar.cm-lisboa.pt/pls/OKUL/f?p=178:16:1750227251188::NO:::

[205] Vázquez, M.A., and Soto, M. (2017) The efficiency of home composting programmes and compost quality, *Waste Management*, Vol.64, pp.39–50

[206] Global Alliance for Incinerator Alternatives (2012) On-the-Road-to-Zero-Waste.pdf

[207] Mckinley, S., and Williams, I.D. (2007) ASSESSING THE ENVIRONMENTAL IMPACTS OF HOME COMPOSTING, p.10

[208] WRAP (2007) *Understanding Food Waste*, 2007

[209] Buck, D. (2016) *Gardens_and_health.pdf*, 2016, https://www.kingsfund.org.uk/sites/default/files/field/field_publication_file/Gardens_and_health.pdf

Community composting is less well developed than in some of the other European countries. [210] A 2007 survey identified 84 organisations involved in collecting/receiving and composting material at 121 sites and processing approximately 20,500 tonnes of material per annum. For the majority of these (60%) composting is an activity that links social and environmental objectives. Composting is carried out alongside non-waste activities such as running community gardens, city farms, local food production, and services for adults with special needs.

There is no way of knowing the quality of management of the home composters, but given that training is required before setting up a community compost site it can be presumed that these sites are being managed optimally. Further they have space for multiple piles so are more likely to be able to create batch piles.

8.2.3 Comparing National Advice on Compost Management

Composting advice is available from range of sources including NGO's, National Government funded waste organisations, city authorities, waste management companies, and compost enthusiasts. This report compares the advice of the National Government funded bodies in the UK, [211] France [212] and Belgium, [213] but relies on Lisbon City Chamber advice for Portugal,[214] a Waste Management Company publication for Finland,[215] and an NGO publication for Spain. [216] All of these sources describe the practices needed to achieve a well-managed pile, but there is no way of verifying if the advice of these organisations represents actual practice in the country concerned.

A key difference in the advice given regards the suitability of meat and fish as material to be included in the compost. Belgium, UK and Portugal recommend not including it while France, Finland and Spain support its inclusion. The Spanish advice goes as far as to say the inclusion of protein rich food is necessary to raise the temperature of the compost[217]

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[210] Slater, R. (2007) *Community Composting Activity in the UK - 2006*, Report for The Open University, 2007, http://oro.open.ac.uk/10289/1/cc_report_Final.pdf

[211] WRAP Recycle Now How to compost.pdf

[212] Reseau Compost Citoyen (2019) *Semaine nationale du compostage de proximité*, accessed 28 October 2019, https://www.semaineducompostage.fr/composter/communication

[213] Brussels Environment (2016) Composter pour réduire ses déchets: Guide pratique, p.30

[214] Lisboa Camara Municipal (2018) Guia Pratico de Compostagem

[215] Paijat-Hame Waste Management (2015) *Kompostointiopas_2015_pienennetty_ID_31440.pdf*, accessed 28 October 2019, http://www.pienennabioberttaa.fi/images/Kompostointiopas_2015_pienennetty_ID_31440.pdf

[216] Zero Waste Europe (2019) *Community Composting: A Practical Guide for Local Management of Biowaste Zero Waste Europe Guides/01*, 2019, https://zerowasteeurope.eu/wp-content/uploads/edd/2019/04/zero_waste_europe_fertile_auro_community_composting_guide_april_2019.pdf

[217] Zero Waste Europe (2019) *Community Composting: A Practical Guide for Local Management of Biowaste Zero Waste Europe Guides/01*, 2019, https://zerowasteeurope.eu/wp-content/uploads/edd/2019/04/zero_waste_europe_fertile_auro_community_composting_guide_april_2019.pdf

—although it is worth pointing out there is no specific evidence for this and the implication would be that garden waste or food waste from vegetarian households would lead to a dysfunctional composting process which is evidently not the case. Small variations in practice are found in the suggested ratio of greens to browns, and in the frequency of turning the pile. These are unlikely to result in significant changes to the outcome of the compost, though interesting to note that the Finnish advice proclaims that turning is not required (which strictly, it isn't, but is still best practice).

The Spanish and Belgian advice recommend having multiple containers to allow turning of the compost and maturation of the compost. This is good practice but easier for community composting sites than home composting. The Portuguese advice pamphlet describes the batch method where the composting material is layered up in one go and then left. This is perhaps misleading for a home composter who is new to composting and not aware that they can also build their pile gradually. The other three publications simplify the instructions and do not offer suggestions on whether to add-as-you-go or build the pile in one go (batch method).

Overall, the national differences in composting advice do not seem to be significant enough to lead to the adoption of different practices in the relevant countries. If followed, the advice given should lead to a well-managed pile in all cases.

There is a marked lack of advice to consumers on how to handle plastic waste in home composting. in some cases, this is because the document predates the prevalence of compostable plastics. Of the sources considered for this report only the French network 'Reseau Compost Citoyen' offers advice on compostable plastics and composting. They present a comprehensive factsheet online discussing compostable bags and other compostable materials such as tableware. [218] This advice shows the OK HOME compost logo and states that materials with this logo can "theoretically be composted in a domestic composter". It states that after 6 months 90% of the bag must be able to pass through a 2mm sieve, giving some indication to the consumer of what they can expect in what time frame, whilst also warning that these items can take longer than expected to 'disappear'. It is suggested that other materials such as plates and cutlery are fragmented before being added to the compost and it also makes the point that products labelled as 'compostable' are not suitable for vermicomposting.

8.2.4 Key Conclusions

Key Conclusions – Comparing Home Composting across six EU countries

[218] Reseau Compost Citoyen (2019) *Semaine nationale du compostage de proximité*, accessed 28 October 2019, https://www.semaineducompostage.fr/composter/communication

A number of Member States have been promoting home composting over the past 20 years though the current extent of home composting is difficult to ascertain as there is little incentive to monitor the practice beyond the impact of particular promotional schemes. Typically, a compost promotion project includes subsidised containers with some form of knowledge provision or advice scheme.

Existing biowaste management

- Waste that is made from organic matter (putrescibles) comprises between 35-40% of Municipal Solid Waste (MSW) in EU Member States.
- Within the capitals of the countries compared biowaste capture rates vary from 0.2% to 42.7% indicating the different levels of maturity of the waste management systems.
- Biowaste collection, when averaged across 28 EU capitals, is reported to be 19.6 kg/cap per annum, which is considerably less than the estimated potential diversion of biowaste from municipal collection into home composting - 150 kg/hhld/yr. A successful community composting scheme in Galicia, Spain collects around 30kg/cap/yr.

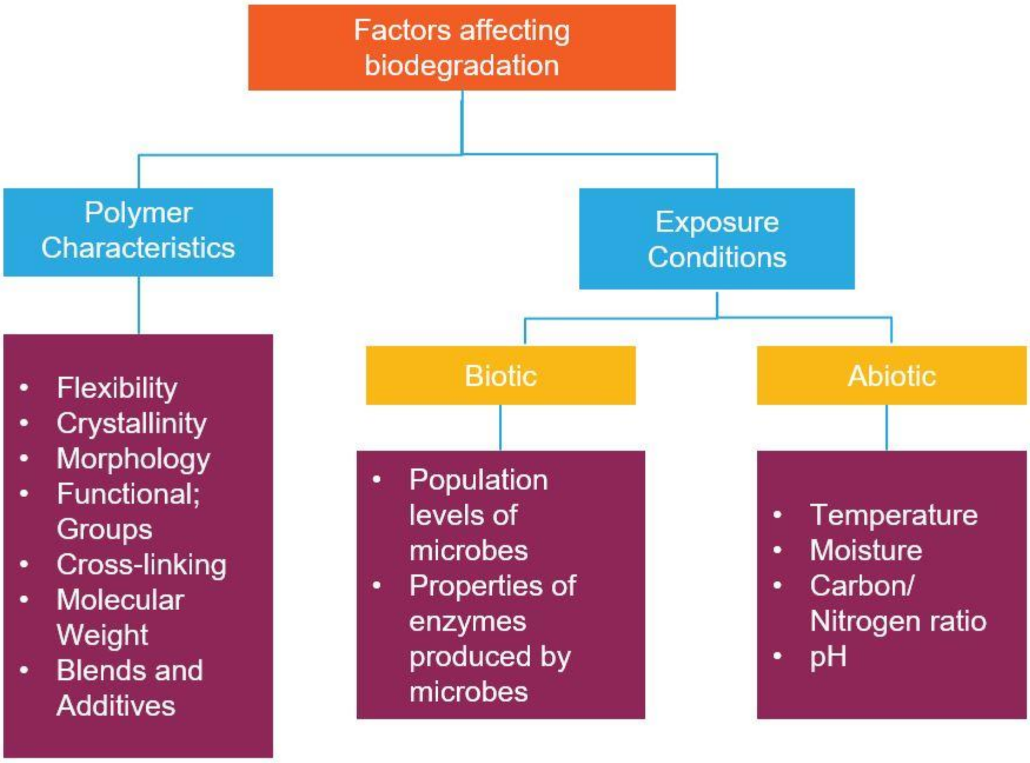
National advice on compost management

- National level composting advice is not always clear in what method it is describing.
- Half the countries considered recommend including meat and fish waste, the other half strongly suggest not to.
- There are wide and varying sources of advice in each country and there is little reason to believe that the advice of the National organisations represents actual practice in the country concerned.
- Overall, the national differences in composting advice do not seem to be significant enough to lead to the adoption of different practices in the relevant countries. If followed, the advice given should lead to a well-managed pile in all cases.
- Only one of the sources of advice compared gave guidance to consumers on how what to expect from composting plastics labelled as 'compostable'. It indicates that there is likely to be a difference in 'theoretical performance' of the materials with actual performance.

8.3 Studying the Conditions Found in Home Composting and their Effect on the Biodegradation of Plastics

In order to understand the potential biodegradation of plastics in a home composting system it is necessary to explore what is known about the biotic and abiotic conditions present in such systems (see Figure 24). The biodegradation process of polymers is affected by two main types of factors – exposure conditions and polymer characteristics, though these interact in several ways. The polymer characteristics determine whether the initial degradation from polymer to polymer fragments is largely chemical or microbial, however the abiotic conditions set the parameters within which this can occur. Polymer characteristics also affect the accessibility of the polymer to microorganisms and the studies which have looked at this are summarised in Section 8.3.4.

Figure 24: Factors affecting biodegradation



Source: Adapted from Kijchavengkul T and Auras R. 2008[219]

8.3.1 Biotic Exposure Conditions in Home Composting

The biotic conditions refer to the variation in microorganisms present and the way in which they consume waste material. Microbes feed on the sugars within the chemical structure of plastics, generating heat, carbon dioxide, water by-products.

In a home compost pile the food waste and garden waste added will already bring microbes to the pile where they can multiply. Further microbes are brought in via macro-organisms such as ants, beetles, centipedes, worms, flies, millipedes, slugs, snails, spiders and woodlice who all find their way into home compost. It is generally the case that microbial levels in in both a well-managed and an add-as-you-go pile are sufficient for composting, and the abiotic conditions should remain within the parameters needed to support the flourishing of these microbes. This is in contrast to soil which can be

[219] Kijchavengkul, T. and Auras, R. Compostability of polymers, *Polym. Int*, Vol.57, No.6, pp.793–804

deficient in microbes.[220] In a well-managed pile that reaches temperatures over 45°C for a sustained period a particular group of microbes (thermophilic bacteria) will flourish, accelerating the composting process.

The enzymes that microbes produce can be specific in what they can digest, with some polymers only being broken down by certain microbes. In most cases however the plastic has to be broken down chemically before microbes can digest the smaller particles. This initial breakdown happens in different ways depending on the characteristics of the polymer, but in many cases needs the presence of water to allow the hydrolysation of certain bonds in the polymer.

8.3.2 Abiotic Conditions in Home Composting

Abiotic conditions impact on the composting process through their effect on microbes, and they vary significantly according to how the compost is managed. The main variables are temperature, moisture, pH and carbon/nitrogen ratio.

In a well-managed pile, the abiotic conditions resemble these shown in Figure 25. The Carbon/Nitrogen ratio fall over time, the ammonium (NH4) levels also fall whilst pH levels rise to a plateau around pH8. Four temperature phases are discernible:

1) **The mesophilic phase** – mesophilic bacteria proliferate as they use carbon in the waste combined with oxygen to produce carbon dioxide and energy. The organic matter begins to be broken down and the temperature of the compost rises to around 45°C.
2) **The thermophilic phase –** as the temperature exceeds around 45°C mesophilic bacteria are inhibited and thermophilic bacteria take over. Temperatures can reach 70°C in this stage.
3) **The cooling phase –** other organisms such as fungi further break down coarser organic material over a period of months.
4) **The curing phase –** This stage is again important in producing safe compost as many human pathogens have a limited period of viability in compost soil.

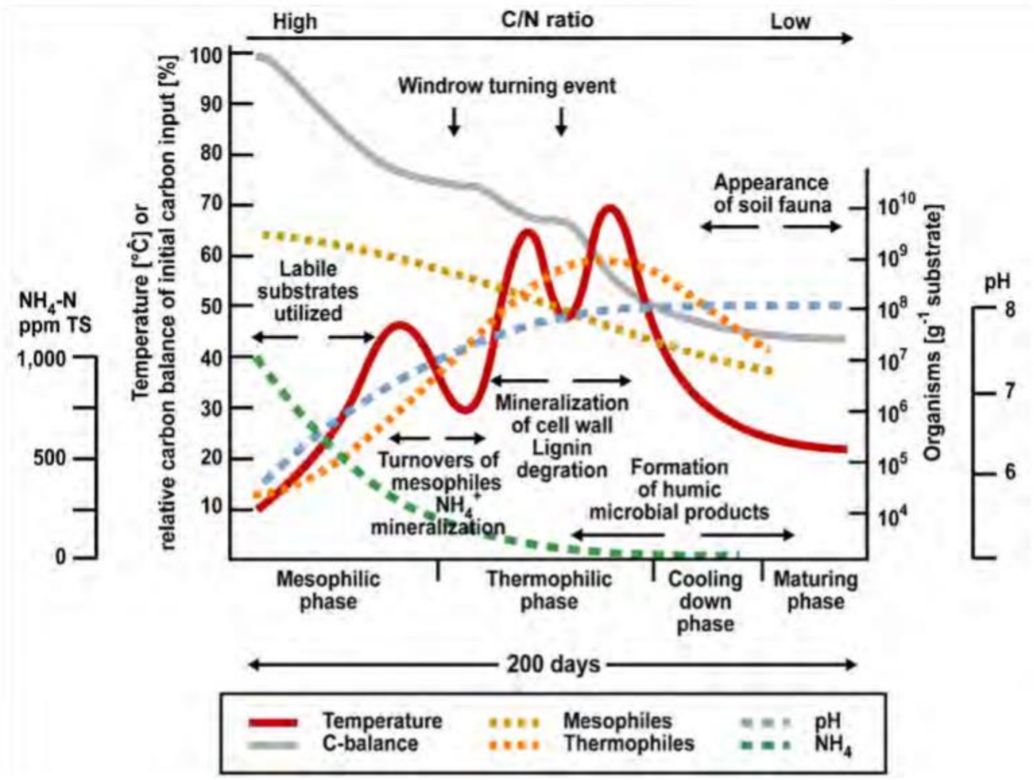
In add-as-you-go home composting, the phases are less distinct and, in some systems, temperatures never reach those expected for the thermophilic phase (>45°C) for sufficiently long enough to allow the flourishing of thermophilic bacteria. This is why home composting is sometimes referred to as a form of ‘cold-composting’ and consequently the breakdown of organic matter is much slower, though the exact process is less well understood than for hot composting

When characterising the conditions in home compost systems it is necessary to consider the profiles of variables over the duration of the composting period, rather than

[220] Wierckx, N., Narancic, T., Eberlein, C., et al. (2018) Plastic Biodegradation: Challenges and Opportunities, in Steffan, R., (ed.), *Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Biodegradation and Bioremediation* (2018) Cham: Springer International Publishing, pp.1–29

absolute levels. This makes it harder to simulate a home composting environment in a laboratory setting.

Figure 25: Conditions within a compost pile over duration of composting process,



Source: Fischer and Glazer 2012[221]

8.3.3 Evidence of Range of Conditions in Home Composting

To determine the range of variation in composting conditions in actual home composting settings a detailed review of eight scientific papers exploring home composting practices has been conducted. The academic studies took detailed measurements of abiotic conditions during the entire composting process. Two papers were included from Argentina and Brazil as they extend the range of ambient temperatures which is of relevance to the extremes of climatic conditions found in Northern and Southern Europe. This report compares these with a study commissioned by the French Environment & Energy Management Agency (ADEME) in 2019,[222] which is the most

[221] Fischer, D., and Glaser, B. (2012) Synergisms between Compost and Biochar for Sustainable Soil Amelioration, in Kumar, S., (ed.), *Management of Organic Waste* (1 February 2012) InTech

[222] Dewolfs, P., Feix, I., Genty, A., et al. (2019) Biodégradabilité En Compostage Domestique Et Industriel Des Sacs Plastiques Biodégradables En Compostage Domestique (Norme Nf T 51-800) Et Des Sacs En Papier, p.35

recent and detailed study of the biodegradability of plastics in home composting settings. The ADEME study did not however record all the variables that the academic studies measured, but is useful in looking at the temperature profile.

Studies included both compost piles managed by the researcher and closely monitored home composting piles managed by householders. The studies primarily used closed containers, with one study also comparing open composting. Table 19 outlines the range of conditions and practices covered in the literature review. A full overview of the papers considered can be found in Appendix A.5.1. This demonstrates that in all of the key variables identified previously, there is a substantial range which provides a good indicator of possible conditions and practices.

Table 19: Range of practices covered in home composting studies

Practice variable	Range
Countries covered	France, Spain, Italy, Sweden, Denmark, Germany, UK, Argentina, Brazil
Ambient temperature range	- 15°C to 36°C
Time period of study	60 days to 13 months
Container capacity	40L to 500L
Feeding regime	kitchen waste, some included meat and dairy, different bulking agents
Weekly weight of feed	1.61kg to 49kg
Mixing regime	no mixing to weekly
Ratio of waste to bulking agent	1:0 to 23:1

Table 20 summarises the range of abiotic conditions across the studies. Though it was not possible to ascertain whether the compost management in these studies fitted the ‘well-managed’ or ‘basic’ management patterns it is useful in providing a broad indication of the range of conditions likely to occur across both management styles.

The following are the key observations from these studies in relation to the:

- Ambient temperature has a large effect on the process of composting, through its impact on microbial activity. However, once activity starts the pile will begin to heat up and this process is influenced more by management practices such as the pattern of feeding and mixing, rather than ambient temperature levels.
- In the studies assessed, ‘cold composting’ was the most common result and where higher temperatures were reached this was only sustained for a couple of days.

- The carbon/nitrogen balance is important, particularly in the cold composting conditions of many home composting systems. This is regulated by feeding the right balance of 'green' and 'brown' materials which requires some degree of knowledge and understanding.
- Moisture level is influential, but it is relatively easier to achieve an acceptable level through appropriate management practices.

Table 20: Range of abiotic conditions found in home composting studies

Abiotic condition	Range in home composting identified
Temperature	Temperatures within pile ranged from 5-70°C
Moisture	Moisture values ranged from 22% to 85%
Carbon/Nitrogen ratio	C/N ratio 10-66
pH level	pH range 5.9-9.28

8.3.4 Evidence for the Behaviour of Plastics Under Home Composting Conditions

There is a paucity of evidence on the behaviour of plastics under home composting conditions. The 2019 ADEME study goes some way to fill this gap and given its significance, the findings will be discussed first, followed by a review of earlier academic studies that have tested compostable plastics under home composting conditions.

8.3.4.1 The 2019 ADEME study

This study, commissioned by ADEME, tested two types of plastic bag, and two types of paper bag, comparing their biodegradation in a variety of different home composting conditions. Disintegration was assessed visually and biodegradation was assessed using Transmission Electron Microscopy (TEM) that can create a visual image of the molecular structure of the material and microbial activity. The home composting process was carefully designed to follow the requirements of the French standard for home composting NF T 51-800 as far as possible. The materials tested were;

- Bag X – 90% PBAT, 9% PLA, 1% green dye
- Bag Y – 70% PBAT, 30% starch

The authors sought to compare the effects of various home composting practices on the biodegradation and fragmentation of the plastic bags. The treatment practices compared included;

- regular mixing of the compost
- doubling up the bags (one inside another)
- placing the bag in the compost filled (with kitchen waste) or empty
- composting in a container compared with a pile in open air
- adding the material into the compost pile in winter compared with spring – the test conditions that began in the winter ran for 18 months, the ones that started in the springtime ran for 12 months.

The practices that were common to all treatment conditions reflect those identified in the present study as a 'well managed' pile with some key differences that may affect the biological processes:

- A container was used in all treatments (but one), but the container size was 800L (almost 1 cubic meter) which is more than double that typically used in a domestic situation. A larger volume of material will support the development of higher temperatures so may result in faster biodegradation rates.
- The composition of material was a 1:1 mix of green (kitchen waste) to brown material (shredded garden waste), and the kitchen waste included meat and fish waste as is the practice in France.
- Regular mixing was performed - weekly for the first month, then monthly. However, the mixing process involved removal of all the material, mixing it then replacing it, which is unlikely to be undertaken in domestic situations and may improve the conditions for biodegradation.
- Lastly, the pile was constructed at the start of the test but no new material was added after this. In domestic situations the regular addition of organic waste is more common. This would also negate some of the benefit of regular mixing as new material would not need to be redistributed around the pile.

The ways in which this study deviates from domestic conditions are likely to produce an environment that is more favourable for biodegradation. In this case the results can be viewed as a 'best case' scenario - indicating that biodegradation should proceed faster than the 'typical' approach to home composting that would be expected.

Overall, the study reported incomplete biodegradation of both the two materials tested over the 18 months duration (Bag X – 90% PBAT, 9% PLA, 1% green dye, Bag Y – 70% PBAT, 30% starch). Fragments of Bag X under 1mm in size were more frequently observed in the final compost than fragments of bag Y, suggesting a lower rate of biodegradation. Transmission Electron Microscopy (TEM) revealed that Bag X was being degraded from within its structure as bacterial activity was observed in the internal layers of the plastic. Bag Y was only being broken down on its surface but it is not clear of the link between this observation and the different rates of biodegradation. The analysis did not give a lot of weight to comparing the performances of the different plastic materials as it seems the main focus of the study was to compare the effects of different composting behaviours on the biodegradation of plastics. The paper bags showed complete disintegration in all the testing conditions.

The results of the visual inspection of the fragments left in the compost are recreated in Table 21 which show that the only testing condition that showed very little residual material was that started in springtime, using a single layer of bag, which was deposited full, and with regular mixing of the compost. However, the authors concluded that "whatever the practice adopted in home composting; it is likely that there will still be visible fragments of the plastics that are deemed 'biodegradable' after 12 months." These results suggest that these materials would not pass the disintegration test included in the country standards for compostable plastics that require 90% of the fragments to pass through a sieve of 2mm within 6 months. While most of the tests show pieces over 2mm it is not clear from the way that the results are recorded what percentage of the material is of this size.

This is problematic, as the message for consumers is complex. The presence of visible fragments of material is likely to raise doubts with the consumer as to whether the product has biodegraded sufficiently. The study conducted a range of tests on the ecotoxicity and quality of the final compost and go on to state that consumers should be 'warned' that the presence of this material does not affect the quality of compost and that the materials used will degrade further in the soil at an undefined time scale. They also found that there were no agronomic benefits to including the plastic at this concentration of 1% as the quality of the compost was not enhanced in any way.

Table 21: Frequency of observed fragments remaining at end of test period

Duration	Mixing	Thickness	Bag full/empty	Size of fragment				
				>20mm	5-20mm	2-5mm	1-2mm	0-1mm*
18 months – Closed Pile	Yes	single	Full	0	+	0	0	3
	Yes	single	Empty	++	0	+	+	24
	Yes	double	Full	+	+	+	0	5
	Yes	double	Empty	+	+	++	++	21
	No	double	Full	++	+	+	+	16
	No	double	Empty	++	0	+	+	6
18 months - Open Pile	Yes	single	Empty	+	+	++	++	27
12 months – Spring start	Yes	single	Full	0	0	0	0	3

Notes:

+ = 1-10 fragments observed

++= more than 10 fragments observed.

*** fragments of this size were observed using a magnifying glass and individually counted.**

Source: Adapted from table 38 in DeWolfs et al.[223]

The findings of the study are also useful in evidencing how certain behavioural practices affect the composting process:

- Mixing of the compost was found to promote higher temperatures in the compost. Where mixing was not undertaken, a lower temperature rise was observed compared with piles that were mixed, resulting in a slowing down of the composting process in all testing conditions.
- Placing the bags into the compost when 'filled' with kitchen waste improves the biodegradation process. It was recorded that the empty bags fragment more slowly and the authors link this to the observation that the filled bags were more likely to be pierced manually with a fork during the mixing process, whereas empty bags were less likely to be caught on the fork. The authors suggest no specific reason why piercing the bag would make a difference—it would introduce minima extra surface area. A more logical explanation may be that the filled bags have more surface area in contact with the waste and a loose bag may stick to itself and effectively loose surface area.
- Using a container for composting supports the composting process by maintaining the temperature of the compost and the activity level of the microbial populations. In this study lower levels of bacterial activity were observed using TEM when composting in the open air and plastic fragments from the bags were still visible after 18 months.
- Starting the composting process in the springtime achieves greater fragmentation of the plastic materials within 12 months, compared with the compost piles that were begun in the winter.

The authors' final conclusion is that the study results "invalidate" the French standard by demonstrating that in home conditions more time is needed for biodegradation than is currently allowed in the test. They also suggest that the testing conditions in the standard should be reconsidered to match the most common home composting conditions or those described in the ADEME composting guidelines. These findings will be revisited in the discussion on differences between composting standards and practice in section 8.5.

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[223] Dewolfs, P., Feix, I., Genty, A., et al. (2019) Biodégradabilité En Compostage Domestique Et Industriel Des Sacs Plastiques Biodégradables En Compostage Domestique (Norme Nf T 51-800) Et Des Sacs En Papier, p.35

8.3.4.2 Earlier studies testing the biodegradability of plastics in home composting

There are a number of earlier studies that claim to report on the biodegradability of plastics under 'natural conditions', [224] and yet the majority of these rely on the ISO laboratory tests for biodegradation such as ISO 14851, ISO 14855 and even the soil test ISO 17566. The scientific literature on biodegradation of plastics is also of limited value as it cannot keep pace with the continually evolving development of new plastic compounds and blends. Many of the peer reviewed studies of a few years ago are testing products that have been superseded by newer compounds.

With these caveats in mind, this report has sought out studies that have actually explored biodegradation of plastics in real life home composting systems. These are detailed in Table 31 and Table 32 in Appendix 5. The usefulness of these are limited by methodological issues and choice of material to be tested. Firstly, three of these studies lasted less than 12 weeks which is understood to be insufficient for home composting to be complete unless it is carefully managed in warm conditions. In these studies, the compost heap was not managed during the study but left undisturbed.

Song's (2009)[225] UK study is methodologically robust, and uses 160L compost containers prepared by following typical advice given to a home composter. Control containers were set up in the same way and all containers were 'turned' monthly at which time samples were taken for analysis. The study ran for 6 months. The results show that PLA, and starch/PCL blends all had a negligible mass loss of <5%. Starch based polymers and plant fibre-based silvergrass were the two substances that showed mass loss of around 80%. Although mass loss is not a direct measurement of biodegradation, it provides an indicator of the relative performance of materials in this regard.

Another study, this time conducted in Germany in 2004 compared open air composting and home composting. Unfortunately, the home composting trials were impeded by the participants failing to follow the instructions, and the results were extremely varied so the author recommended they were indicative only. The composting trials monitored by the author found that only the starch-based products showed complete degradation.

A test in Greece simulated home composting over 11 months. A 100L container (containing a sheep manure/sawdust ratio of 5:1) was used with ambient temperatures of 5-17°C and humidity of between 45-60% w/w. Internal temperatures reached above 35°C for 4 days in the first week. The PLA film samples showed very little disintegration over the 7 weeks of the composting test, after which point the authors deemed that the compost had passed the 'active' phase, although this is a much shorter period than

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[224] Emadian, S.M., Onay, T.T., and Demirel, B. (2017) Biodegradation of bioplastics in natural environments, *Waste Management*, Vol.59, pp.526–536

[225] Song, J.H., Murphy, R.J., Narayan, R., and Davies, G.B.H. (2009) Biodegradable and compostable alternatives to conventional plastics, *Philosophical Transactions of the Royal Society B: Biological Sciences*, Vol.364, No.1526, pp.2127–2139

typically found in home composting. The results indicate that PLA will not disintegrate sufficiently fast in domestic composting piles since the minimum required conditions are typically not met. [226]

PLA has hydrolysable functional groups in its main chain (ester bonds). It has been found that the hydrolysis of these ester bonds is the main route of PLA degradation, and that a temperature of 60°C is needed for this to occur. [227] This high temperature is closely related to the glass transition temperature (Tg) of PLA due to its high molecular weight. When a temperature of 60°C is present water can diffuse through the polymer of PLA and bulk erosion occurs as the polymer starts to degrade through its cross section. This breaks it into smaller units which diffuse out of the polymer bulk to the surface where they are consumed by microorganisms.

Experimental studies have simulated the 'ideal conditions' for PLA breakdown reporting a range of results. Between 2006 and 2014 eight laboratory studies used an inoculum that included compost and were kept at a minimum of 58°C for 28 days. The biodegradation, as measured by CO_2 production or weight loss, ranged from 13% to 100% showing that even in 'ideal conditions' total biodegradation of PLA is hard to achieve.[228]

PHA is one plastic that is thought to be more suitable for home composting. There are more than 150 PHA monomers, with a great diversity in material properties. Their crystallinity ranges from 30% to 70%, and melting temperature ranges from 50°C to 180°C.[229] In contrast to PLA, the primary degradation of PHA occurs at its surface where it is attacked by various enzymes which are secreted by microorganisms. [230] A key group of enzymes are the depolymerases but different microorganisms produce different enzymes and can degrade different types of PHA depending on their internal structure. The enzyme specificity of certain polymers is currently being explored in a number of studies, but the prevalence of these enzymes in home compost has yet to be identified. Temperature again affects the biodegradation process with an increased rate of

[226] Rudnik, E., and Briassoulis, D. (2011) Degradation Behaviour of Poly(lactic Acid) Films and Fibres in Soil Under Mediterranean Field Conditions and Laboratory Simulations Testing, *Industrial Crops and Products*, Vol.33, No.3, pp.648–658

[227] Agarwal, M., Koelling, K.W., and Chalmers, J.J. (1998) Characterization of the Degradation of Polylactic Acid Polymer in a Solid Substrate Environment, *Biotechnology Progress*, Vol.14, No.3, pp.517–526

[228] Emadian, S.M., Onay, T.T., and Demirel, B. (2017) Biodegradation of bioplastics in natural environments, *Waste Management*, Vol.59, pp.526–536

[229] Wierckx, N., Narancic, T., Eberlein, C., et al. (2018) Plastic Biodegradation: Challenges and Opportunities, in Steffan, R., (ed.), *Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Biodegradation and Bioremediation* (2018) Cham: Springer International Publishing, pp.1–29

[230] Wierckx, N., Narancic, T., Eberlein, C., et al. (2018) Plastic Biodegradation: Challenges and Opportunities, in Steffan, R., (ed.), *Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Biodegradation and Bioremediation* (2018) Cham: Springer International Publishing, pp.1–29

biodegradation of PCL, PHB and PHBV reported at 46°C than 24°C when incubated in compost mixtures. [231]

Studies of PHA degradation in real-life conditions at low temperatures have shown reported biodegradation rates of 35-48% in soil.[232] [233] One study found that a degradation rate of 90% was achievable when the PHA was blended with rice husks in the ratio of 60:40 suggesting that further research into the effect of blends on plastics biodegradability is needed. The microbial specificity of certain plastics also limits their biodegradation in home composting settings.

The main conclusions that can be drawn from the current limited research is that PLA will not fully biodegrade in home composting, as it needs temperatures above 60°C before biodegradation is initiated. There is evidence that PHA, particularly when blended, with starch compounds, will biodegrade to some extent under low temperature conditions, however there has been no direct testing of this in home composting trials. The only materials that have shown high degree of biodegradation in home composting studies are the starch-based products, but the limited evidence base means that no firm conclusions can be drawn at this stage.

8.3.5 Key Conclusions

Key Conclusions – Conditions in home composting affecting biodegradation of plastics
In order to understand the potential biodegradation of plastics in a home composting system it is necessary to explore what is known about the biotic and abiotic conditions present in such systems. The biodegradation process of polymers is affected by two main types of factors – exposure conditions and polymer characteristics, though these interact in several ways. The polymer characteristics which determine whether the initial degradation from polymer to polymer fragments is largely chemical or microbial, however the exposure conditions set the parameters within which this can occur. Polymer characteristics also affect which microbes are most active in the mineralisation stage.

[231] Lotto, N.T., Calil, M.R., Guedes, C.G.F., and Rosa, D.S. (2004) The effect of temperature on the biodegradation test, *Materials Science and Engineering: C*, Vol.24, No.5, pp.659–662

[232] Gómez, E.F., and Michel, F.C. (2013) Biodegradability of conventional and bio-based plastics and natural fiber composites during composting, anaerobic digestion and long-term soil incubation, *Polymer Degradation and Stability*, Vol.98, No.12, pp.2583–2591

[233] Wu, C.-S. (2014) Preparation and Characterization of Polyhydroxyalkanoate Bioplastic-Based Green Renewable Composites from Rice Husk, *Journal of Polymers and the Environment*, Vol.22, No.3, pp.384–392

In terms of the **biotic exposure conditions** using fresh garden waste in a home compost pile ensures that microbial levels in both a well-managed and an add-as-you-go pile are sufficient for composting. This is in contrast to soil which can be deficient in microbes.

In a well-managed pile that reaches temperatures over 45°C for a sustained period a particular group of microbes (thermophilic bacteria) flourish, which accelerates the composting process.

In terms of **the abiotic exposure conditions,** these important in how they affect the health of the microbial population. Ambient temperature has a large effect on the process of composting, through its impact on microbial activity. However, once activity starts the pile will begin to heat up and this process is influenced more by management practices such as the pattern of feeding and mixing, rather than ambient temperature levels. The carbon/nitrogen balance is important, particularly in the cold composting conditions of many home composting systems. This is regulated by feeding the right balance of 'green' and 'brown' materials which requires some degree of knowledge and understanding. Moisture level is influential, but it is relatively easier to achieve an acceptable level through appropriate management practices.

There is a lack of robust studies that test how plastics behave under home composting conditions. This report identified 6 studies that attempted to measure biodegradation of plastics in home composting conditions, but they are limited in their usefulness, mostly due to methodological weakness in study design such as shortness of testing period. In addition, a number of studies claim to report on the biodegradability of plastics under 'natural conditions', yet are of little relevance to this study as they rely on the ISO laboratory tests for biodegradation rather than testing within an actual home compost system.

Given the low temperature conditions of many home composting systems PLA is not home compostable. Other plastics (PHA, polyesters and blends) show some degree of chemical biodegradation at lower temperatures according to their polymer characteristics, but there has been no direct testing of their biodegradation in home composting systems. The microbial specificity of certain plastics also limits their biodegradation in home composting settings.

A 2019 ADEME study from France provides useful evidence of the behaviour of compostable food waste bags in home composting conditions and is the most comprehensive study of its kind. The two bag types— PBAT/Starch and PBAT/PLA blends—were added to the compost at a concentration of 1%. The use of a very large 1sqm pile that was created at the beginning (rather than continuously added to) meant that the study reflects conditions that are far more optimal that may be found in reality; despite this, the study found that:

- incomplete biodegradation (with visible fragments) both bags was reported after 18 months;
- fragments of plastic material are likely to be still present in the compost after 18 months;

- there were no ecotoxicity concerns from the resulting compost, but neither were there any agronomic benefits from including the plastic material; and,
- paper bags equivalents were shown to biodegrade in a much shorter timeframe with no visible residues.

Behavioural factors were also found to be a significant factor in the speed of the biodegradation process with the following found to speed up the process:

- Depositing the biowaste bag full, rather than empty
- Regular mixing of the pile
- Starting the pile in springtime not winter

8.4 Standards and Certifications for Home Composting of Plastics

Standards for compostable products currently exist only for industrial composting at a European level (EN 13432 and EN 14995). There are no European (CEN), international (ISO) or American (ASTM) standards for home composting to date though a draft standard has been written by CEN specific to carrier bags: "Requirements and test scheme for carrier bags suitable for treatment in well-managed home composting installations." This section will analyse the different standards by looking in detail at the testing criteria on which they are based.

8.4.1 Specifications of Test Methods

The suite of ISO tests are the building blocks of the country level and EU level standards. The tests define in detail the testing procedures for biodegradation, disintegration and toxicity effects. Tests differ in the choice of inoculum (microbially active medium e.g. soil, compost etc.) and the measurement methods for recording the biodegradation and disintegration levels. (e.g. ISO 14851 – oxygen demand and ISO 14852 – evolved carbon dioxide). Table 31 and Table 32 in Appendix 5 detail the current biodegradation and disintegration tests.

Biodegradation is thought of as a property of a material, but it is also a property of a system; the conditions of the system determining whether the material will biodegrade. [234] The purpose of lab testing is to show the inherent nature of the material to biodegrade under a given set of conditions which is defined in ISO 14855 as a:

[234] Renewable lube (2019) *Understanding Biobased/Biodegradable and the Industry's Standardized Tests and Definitions*, accessed 28 October 2019, http://renewablelube.com/files/4514/4734/8222/standardized.pdf

"breakdown of an organic compound by microorganisms in the presence of oxygen into carbon dioxide, water and mineral salts of any other elements present (mineralization) plus new biomass."

The test measures the carbon dioxide evolved and compares this with the theoretical maximum amount of carbon dioxide that the material could produce. This is also compared to a cellulose reference material tested under the same conditions for which the test is deemed invalid if the reference material doesn't reach certain levels of biodegradation.

The most commonly used test for biodegradation is ISO 14855 (Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions). The test simulates intensive aerobic composting conditions as is found in industrial composting facilities. The test material is mixed with a stabilised, mature compost derived from the organic fraction of municipal solid waste (the inoculum). The mixture is incubated at a constant temperature of 58°C ± 2°C until a plateau phase of biodegradation is recorded, which should be no more than 6 months.

The type of inoculum used in a test will impact on the biodegradation process. ISO 14855 states that:

"Well aerated compost from a ***properly operating aerobic composting plant*** *shall be used as the inoculum…It is recommended that compost from a plant composting the organic fraction of solid municipal waste be used in order to ensure sufficient diversity of microorganisms. The* ***age of the compost should preferably be between 2 and 4 months.****"*

The age of the compost is important here; as discussed in Section 4.2.1 the maturity of the compost dictates the level of biological activity present. In this case, compost of 2-4 months in age is still very biologically active and would be considered as 'fresh compost' under the German Rottegrad system. In using ISO 14855 it has been found that using the specified inoculum can result in the release of extra CO_2, confusing the results as CO_2 production is the key indicator of biodegradability. This is known as the 'priming effect.' [235] A 2018 revision to ISO 14855 introduced an alternative test method to remove this problem by using a solid mineral medium such as vermiculite inoculated with thermophilic microorganisms obtained from compost.

Certain substances will not be suitable for testing with ISO 14855, particularly colouring inks, additives or colourants. In these cases, the alternative tests ISO 14851 and 14852 have been designed which test within an aqueous medium. The inoculum is derived from activated sludge, compost or soil. Biodegradation is measured either through the analysis of evolved carbon dioxide (ISO 14852) or through the consumption of oxygen (ISO 14851).

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[235] Bellia, G., Tosin, M., and Degli Innocenti, F. (2000) Test method of composting in vermiculite is unaffected by the priming effect, *Polymer Degradation and Stability - POLYM DEGRAD STABIL*, Vol.69, pp.113–120

ISO 17556 is another biodegradation test that can be used for some plastic materials but it uses a soil inoculum and measures biodegradation by the amount of oxygen consumed rather than by the amount of evolved carbon. Using soil means that the inoculum is likely to be less biologically active than a mature compost, but as the soil can be taken from anywhere, this is difficult to verify.

Disintegration of plastics are tested using ISO 16929 and ISO 20200. ISO 16929 takes pieces of the sample material that are 5cm x 5cm (or 10cm x 10cm for films) and places them in a pilot scale compost bin of minimum volume 140L. The compost bin is filled with a homogenous biowaste of the same age and origin with the addition of 10-60% bulking agent. The compost is turned weekly during the first 4 weeks of the test, then fortnightly until the end of the test. (12 weeks in total) The mixture is then passed through a 10mm sieve followed by a 2mm sieve to pick out remaining particles of the test material. These are visually inspected. ISO 20200 differs in that it uses a laboratory scale test with a synthetic solid waste inoculated with mature compost. The degree of disintegration is calculated quantitatively by comparing the initial dry mass of the material with the dry mass of residual material that didn't pass through the sieve—this particular task requires a high level of training and skill to accurately identity fragments within the compost.

8.4.2 Country Level Standards

Australia is the only non-European country to have produced a home composting standard (AS 5810-2010) and they describe the challenges in developing this:

> *"**Home composting systems vary considerably** in their design, construction and operation; hence **their performance also varies considerably** compared to commercial composting facilities. Consequently, this Standard, in comparison to AS 4736 [for industrial composting], uses **lower temperatures** in test environments and a **longer test duration**, to account for such variations in home composting performance."*

Within Europe, France, Italy and Belgium are the only countries to have developed their own standards. The Belgian standard is called a decree yet it has the same legal standing as the others.[236] Table 22 shows the requirements of these standards and how the testing regimes within them make use of the suite of ISO tests. The table also includes the draft CEN for carrier bags in home composting.

In the key aspects the Australian, French and Belgian standards are in broad agreement, being largely based on EN 13432 with the following adaptations.

- **Biodegradation:** Temperature restricted to 20-30 °C, time for reaching 90% biodegradation is extended to 12 months

[236] Le Ministre du Climat et de l'Energie, and P. MAGNETTE (2008) Belgian Official Gazette - 24.10.2008 - MONITEUR BELGE 56651

- **Disintegration:** Time for reaching 90% <2mm is extended to 6 months
- **Ecotoxicity:** Limits on heavy metals and plant germination testing

The Italian Standard differs slightly in its requirements, in part because it is not strictly speaking a home-composting standard, rather it serves to certify biodegradable plastics at ambient temperatures. It specifies;

- Biodegradation:
    - that the biodegradation test takes place in soil rather than compost; ISO 17556
    - a tighter temperature range but still within the boundaries of the other standards (21-28°C rather than 20-30°C)
    - a second stage of testing if 90% biodegradation is not reached in 12 months. The sample can be tested using the same test method with the industrial composting threshold which has lower requirements (i.e. at 58°c for 6 months);
- Disintegration: no test specified
- Ecotoxicity: the requirements are stronger as it specifies the use of an earthworm survival test

In specifying the use of ISO 17556 (Determination of the ultimate aerobic biodegradability of plastic materials in soil) in the Italian standard this is in some ways a stricter test as soil is a less biologically active medium than compost so biodegradation is likely to be slower. This may be why the Italian standard allows for a secondary stage of testing using the industrial composting test if the initial soil test only demonstrated biodegradation of between 60-90%.

However, this seems to allow a loop hole for some products to pass through as a material that is proven to be industrial compostable only has to reach 60% biodegradation in 12 months in soil conditions. It is not clear whether this is an intentional weakening of the standard or an oversight. Certainly, without using the same compost laboratory test as the other country standards it is difficult to draw a direct comparison of stringency.

The Australian and Italian standards are the only ones that require ecotoxicity testing on earthworms rather than the more basic germination tests that are required in EN 13432. Notably the French standard states that this test is *"…not considered to be a distinguishing criterion",* suggesting that a plastic could still be classified as 'home compostable' even if it failed the ecotoxicity test.

It is unclear why the French standard takes this position and from a precautionary principle perspective is could be argued that reducing the risk of any ecotoxicological impacts should be a priority for any such standard. It may be that low concentrations of compostable plastics in home compost pose a relatively low risk, but low concentrations cannot be assumed especially if products using these materials become more available—appropriate testing should remove the risk at any concentration level.

All standards require tight limits on heavy metals in the materials to be tested, with France also limiting Cobalt. The French standard also has several other prerequisites, including the following:

> *"If a plastic product is made up of different components, some of which are compostable by home compostable while others are not, the product itself shall not be identified as "suitable for home composting"."*
>
> *"If a plastic product is printed, it may be designated as "suitable for home composting" only if it has been assessed taking into account the inks used."*

These requirements highlight the importance that the entire product (including inks) is home compostable to reduce the risk of non-compostable materials being placed in home composting.

The Belgian decree is the only one that specifically states that the standard does not apply to 'worm composting'—all of the other standards, whether they include a worm test or not, do not differentiate between or specify which kind of composting system the requirements are set for. This could be an issue in the future if indoor composting becomes more common.

Table 22: Home Compostable Plastic Standards and certifications

Orange Text = weaker requirement, Green text = stronger requirement

Standard	Limitation of heavy metals	<5% non-bio-degradable substances?	Biodegradation Tests	Pass at: >90% degradation in 12 months	Dis-integration tests	Pass at: 90% <2mm in 6 months	Ecotoxicity tests
FRANCE: T 51-800. Plastics — Specifications for plastics suitable for home composting	As for EN13432 also Cobalt	Allowed	ISO 14855 and ISO 14851/52 But temp restricted to 20-30°C and duration lengthened to 12 months	Yes	ISO 16929 but at 20-30°C, 6 months	Yes	Aligned to EN13432 (germination rate)
BELGIUM: Product standards for compostable and biodegradable materials	As for EN13432	Allowed	As for French standard with addition of **ISO 17556 (soil)**	Yes	As for French Standard	Yes	As for French Standard
ITALY: UNI 11183. Biodegradable plastics at ambient temperature	As for EN13432	**Unclear**	As for French standard with addition of **ISO 17556 (soil)** But at **21-28°C**	**If rate is 60-90% then use 14855 at 58°C**	**None**	**None**	UNI 10780 (germination rate) **ISO 11268 (earthworm)**
AUSTRALIA: AS 5810—2010 Biodegradable plastics suitable for home composting	As for EN13432	Allowed	As for French standard	Yes	ISO 20200 at 20-30°C, 6 months	Yes	Aligned to EN13432 (germination rate) **ASTM E1676 (earthworm)**
DRAFT CEN: Packaging — Requirements and test scheme for carrier bags suitable for treatment in well-managed home composting installations	CEN/TR 13695-2;	Allowed	As for French standard with addition of **ISO 17556 (soil)**	Yes	IN DRAFT 20-30°C, 6 months	Yes	**EN ISO 11269-2 – plants** **EN ISO 11268-1 – earthworms – acute and chronic effects** **ISO 15685 - bacteria**

8.4.3 Draft European CEN Standard for Home Composting of Plastic Carrier Bags

There are two new forthcoming CEN standards that are in the process of being agreed with a view to being published in 2020:

- **EN 17427:** Packaging — Requirements and test scheme for carrier bags suitable for treatment in well-managed home composting installations
- **EN 17428:** Packaging — Determination of the degree of disintegration under simulated home composting conditions

The aim of EN 17427 is to move beyond the current reliance on EN 13432 as a benchmark for plastic compostability and define “the characteristics carrier bags must own in order to display biodegradation and disintegration behaviour compatible with well-managed home composting installations.” Central to this is the definition of a well-managed home composting installation. This can raise potential issues as the definition of a well-managed home composting system does not acknowledge that many successful home composters will be using a more minimal system; the distinction between a well-managed pile and a minimally-managed pile is not clearly addressed in any current standard and is mentioned only in passing in the draft CEN standard.

A key area in which EN 17427 moves beyond its predecessors is in defining the characterisation of carrier bags that are to be tested. The maximum concentration of regulated heavy metals follows the same limits as EN 13432 but in addition per- and poly-fluorinated substances (PFCs) are not permitted to be intentionally added to the material of the bag. Similarly, substances of very high concern (SoVHC) cannot be intentionally added and must not exceed a concentration of 0.1%. Substances hazardous to the environment shall be identified and assessed according to CEN/TR 13695-2. [237]

The biodegradability criteria broadly follow those adopted by existing country standards in specifying that the temperature during testing should be restricted to 25°C ± 5°C and testing should last for up to 12 months. The biodegradation criteria are further strengthened by stipulating that any organic constituent present in more than 1% of dry mass of the bag needs to also be tested for biodegradability. Such constituents cannot exceed 15% in total. This is a very important addition as there are unconfirmed reports (from multiple reliable and independent sources that cannot be named) of manufacturers using the current threshold of 90% measured biodegradation in EN 13432 to include up to 10% non-biodegradable materials in order to achieve superior mechanical properties whilst lowering costs. This new requirement effectively prohibits this ‘loop hole’.

Ecotoxicity tests are included for negative effects on plant growth and germination (as for EN13432), but with new requirements for tests on the effects on earthworms, and on

[237] CEN (2004) CEN_TR_13695-2{2004}_(E).pdf

bacteria through a nitrification inhibition test. The inclusion of tests on ecotoxicity are important to ensure that the compost produced in a home setting containing biodegraded plastic is not harmful to the natural environment in unforeseen ways. The addition of the test for adverse effects on earthworms represents a more stringent testing requirement and brings ecotoxicity testing in line with EN 17033 for biodegradable mulch films.

The new disintegration test being developed (EN 17428) alongside, differs from earlier disintegration tests as it attempts to define a laboratory scale test that simulates aerobic home composting conditions, to replace the pilot scale composting specified in ISO 16929 which used a 140L bin. The new test specifies that the container (composting reactor) should be 5-10L in size and the test material should be cut to between 2.5x2.5cm and 5x5cm in size. The test does allow for alternative testing 'in situ' but does not currently define a standard method for field testing under home composting conditions and in practice it is unlikely this will be an attractive option for cost and practicality reasons.

Limiting the scope of the draft CEN to carrier bags also demonstrates the trend to produce product specific standards that help reduce the occurrence of unintended consequences (e.g. certifying plastic bottles). However, this does presuppose that it is acceptable that carrier bags, as a product, can and should be placed in home composting if certified.

8.4.4 Certifications

There are two main industry bodies certifying products as suitable for home composting: TUV Austria and Din Certco.

The Din Certco DIN-Geprüft Home Compostable label and certification can be used for any product that passes either the Australian or France standards.

TUV OK compost HOME currently has 787 certificates issued for products passing its home composting tests. [238] This certification and associated label is not linked to other home composting standards but uses EN 13432 as the basis but with their own variations deemed appropriate for home composting:

- **Biodegradation:** Temperature restricted to 20-30 °C, time for reaching 90% biodegradation is extended to 12 months
- **Disintegration:** Time for reaching 90% <2mm is extended to 6 months

TUV OK compost HOME certification does not include all of the additional elements that have been identified in the draft CEN standard and therefore it is assessed to be weaker (in the same way the country level standards are) with regard to the disintegration test, the 'loop hole' for non-biodegradable materials and ecotoxicity tests.

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[238] TUV Austria (2019) *Certified Products*, accessed 29 October 2019, http://www.tuv-at.be/green-marks/certified-products/

8.4.5 Key Conclusions

Key Conclusions – Standards and Certifications for Home Composting

Specifications of Test Methods

The suite of ISO tests are the building blocks of the country level and EU level standards. The tests define in detail the testing procedures for biodegradation, disintegration and toxicity effects. Tests differ in the choice of inoculum (microbially active medium) and the measurement methods for recording the biodegradation and disintegration levels.

- The choice of inoculum is important in testing biodegradation processes. The primary test for biodegradation ISO 14855 uses an inoculum derived from industrial compost but the maturity of this can affect results
- The European CEN standards reference the use of these tests but also stipulate what test result indicates a valid result

Country Level Standards

National standards for home composting have been are currently available in France, Belgium, Italy and Australia. There are no European (CEN), international (ISO) or American (ASTM) standards for home composting to date.

In the following key aspects all of standards are in broad agreement:

- **Testing temperature:** 20-30ºC
- **Biodegradation threshold:** 90% in 12 months
- **Disintegration threshold**: 90% <2mm in 6 months
- **Ecotoxicity:** Tests are generally (with the exception of Australia and Italy) not stricter than for EN 13432 and do not include any testing to determine toxicity to invertebrates such as worms.

Industry certifications, TUV OK compost HOME and the Din Certco DIN-Geprüft Home Compostable, also follow the same requirements as country standards.

Draft European CEN Standard for Home Composting of Plastic Carrier Bags

The European Committee for Standardization (CEN) is also developing its own Standard which aims to build on the current country standards. The Standard is currently in draft form, but its scope is narrower in that **it is only applicable to plastic carrier bags** at this stage— this recognises the increasing need to develop product specific standards for biodegradation, but it is yet to be determined whether the implicit promotion of this particular application is justified.

The current draft is stricter that current Standards in the following areas:

- **Characterisation –** restrictions on Substances of Very High Concern, substances hazardous to the environment and per and poly-fluorinated substances.

- **Biodegradation -** any organic constituent present in more than 1% of dry mass of the bag also needs to be tested and pass for biodegradability. Such constituents cannot exceed 15% in total.
- **Disintegration –** a new test is introduced (and accompanying CEN standard) for laboratory scale simulation of the aerobic home composting process
- **Ecotoxicity -** Tests are now included for effects on earthworms, and possible effects on bacteria through a nitrification inhibition test.
- **Ecotoxicity -** Tests are included for negative effects on plant growth (as for EN13432), earthworms, and possible effects on bacteria through a nitrification inhibition test.

8.5 Comparison Between Standards and Actual Home Composting Conditions

The draft CEN standard for home composting of carrier bags has gone some way to match testing conditions with those found in home composting systems. It is also the strongest requirements of any standard to date and, if introduced, is likely to become the de facto standard in the EU for compostable carrier bags. For this reason, the focus of this section is primarily on the draft CEN standard.

8.5.1 Differences Between Home Composting Conditions and Test Conditions

The testing conditions need to be limited in order to facilitate the measurement of biodegradation in a scientific, replicable, manner. The tests do however try to approximate the conditions in typical home composting systems and in some key areas there is still room for discussion around whether the testing conditions are sufficiently replicating the home environment.

The most important aspect that should be considered in the differences between testing and actual conditions in home composting are:

1) **Duration.** The duration of all the home composting tests is 12 months which is comparable with the length of time that home composters should expect their compost to be ready for use if they are adopting a *basic management practice* resulting in *cold composting* (as indicated earlier in Table 16). If they manage the compost efficiently it could be complete in several months. The key here is that the plastics in a household composter should compost at the same rate (or faster) as the rest of the waste in the compost pile—as the testing is always verified in comparison to cellulose which is itself a more readily biodegradable substance than much of what ends up in a home composter. In very cold climates, composters who let their compost go dormant over winter (i.e. do not actively manage it) will already know and expect that the composting process may need two summer cycles to mature. A compostable plastic being treated in such a home compost system could also take that long but is still keeping pace

with the rest of the biowaste and therefore the expectations of the householder. The results of the ADEME study show that it is possible that fragments of plastic material will remain in the compost after 12 months, even when the rest of the organic material becomes compost.

2) **Temperature.** Temperature is closely related to duration. The draft CEN standard and the country standards restrict the temperature of the testing environment to 20°- 30°C which is to reflect the conditions that low temperature mesophilic bacteria thrive in. **This recognises that a lower test temperature will only reduce bacterial activity, not stop it.** Across the home composting studies identified for this report it was observed that during the biologically active phase of the composting process it is the microbial action that determines temperatures within the compost, not the ambient temperature, and higher temperatures (thermophilic) can be reached. After this initial phase the compost temperature closely follows the ambient temperature levels within a few degrees which is usually a satisfactory temperature range for mesophilic bacteria to be active and biodegradation to finalise. With the results of the ADEME study showing that visible fragments remain even after 12 months, **reducing testing temperature to reflect sub optimal conditions (in the range of 15-25ºC) should be something that is considered**. Of equal importance is that consumer expectations are aligned with the outcomes i.e. if they live in colder climates, full biodegradation may take longer (for all materials in the compost, not just plastics).
3) **Inoculum.** The laboratory scale test relies on the use of an inoculum made from industrially produced compost matured up to 4 months. Although this inoculum is not directly representative of the home compost environment, it presents a *less active* microbial environment than would be found in real life home compost with fresh matter. In this way, it can be considered a stronger test compared with using fresh compost or even many types of soil which can be highly biologically active.
   However, the matter is further complicated by the requirement in testing conditions for the new disintegration testing standard (prEN 17428) that the inoculum material (mature compost) is to be sieved to fragments between 5mm and 10mm. The authors of the ADEME study point out that this increases the contact surface between the testing material and the inoculum, optimising the conditions for biodegradation. In home composting the base material will never be sifted in this way and the fragments will be much larger.
4) **Form of the testing material.** The disintegration testing standard (prEN 17428) specify that the material should be reduced in size to between 2.5 cm × 2.5 cm and 5 cm × 5 cm. When in home composting the materials will be in their full final product form. This can raise many issues—for example, bags may be deposited tied up and closed, full or empty. These all affect the speed of the biodegradation process.

8.5.2 Defining the Scope of Home Composting Practices for which Standards are Valid

The actual performance of home compostable plastics is greatly influenced by several factors, many of which are behavioural. These include:

- Behavioural variation in practice between countries
    - Cultural differences in practice due to climatic factors
    - cultural differences in acceptability of including meat and fish waste
- Variation in quality of practice (maintaining a 'well-managed' pile vs a 'basic' pile vs dumping of organic waste with little management)
- The increasing prevalence of other practices that are referred to as 'home composting' which will not provide the same abiotic conditions for biodegradation and disintegration (Vermicomposting and Bokashi – fermenting).
- How the product is presented into the compost pile (e.g. closing a bag prior to composting)

These behavioural issues all add to the variation of conditions likely to exist in home composting systems. Although these factors clearly sit beyond the responsibility of the standard setting bodies, the variation in outcome that they bring could seriously undermine consumer trust in the certification/labelling process if products that are labelled as home compostable do not meet expectations.

One of the potential reasons why there may be a discrepancy between tested products biodegradability in the laboratory and in a home setting could be because of a lack of clarity in defining the home composting system that the tests are valid for. To this end the draft CEN standard defines the scope of the test as applicable to "a well-managed home compost system". The document defines 'well-managed' home composting as a "home composting practice which meets the minimum required conditions to convert biowaste into compost" [239]. Annex E of the standard goes on to offer guidelines for 'optimal' composting:

Optimal composting can be achieved by ensuring:

- sufficient air and moisture are present in the rotting heap,
- roughly textured compost raw materials (e.g. branches) are mechanically shredded before composting, and
- the composition of the compost raw materials fulfils the nutritional requirements of the microorganisms.

Later in the text it also states that

- The rotting material should feel moist but not wet.

[239] P8 CEN (2019) CEN-TC261-SC4-WG2_N0296_Home_compostable_bags_Text_submitted_to_enquiry_clean_version.pdf

- In order to ensure sufficient air, the compost heap might need to be turned manually or aerated by other means.

These guidelines, while covering the main points of this report's definition of a 'well-managed' pile (see Table 16) appear to conflate the ideal management practices that a home composter needs to carry out with the description of conditions that these practices will encourage. Furthermore, the guidelines acknowledge that there are two possible routes to successful home composting, but the differences are oversimplified by aligning ***batch composting*** with a ***hot composting*** process and ***add-as-you-go composting*** with a ***cold composting*** process. This is inconsistent with the conclusions of the research for the current study which finds that add-as-you-go composting can also produce a hot process if managed correctly, as is regularly demonstrated in the success of community composting.

8.5.3 Key Conclusions

Key Conclusions - Comparison Between Standards and Actual Home Composting Conditions
Whilst biodegradation Standards are always aimed at testing for 'inherent biodegradability', this concept has less credibility when applied to environmental conditions that are more influenced by local climate and microbial life. At very least it is important to ascertain whether the timescales in the Standards (12 months) are realistic and what might influence this. This will help to demine whether Standard is fit for purpose and how this can be communicated to end-users in order to manage their expectations. The main ways that home composting conditions differ to test conditions are: 1) **Duration –** The results of the ADEME study show that that fragments of plastic material can remain in the compost after 12 months, even when the rest of the organic material becomes compost. 1) **Temperature –** It is clear that the testing temperatures do not reflect actual real life conditions. Lower ambient temperatures (i.e. <20°C) will see slower biodegradation taking place. The effects should be explored of changing the testing temperature to something that mirrors the conditions in a temperate climate, but still allowing for microbial activity to occur i.e. not lower than 10°C. 2) **Inoculum-** The tests use a mature compost that is likely to be less biologically active than fresh garden waste that a householder will use—i.e. the test is harder to pass. However, the test inoculum is sieved, which may speed up the biodegradation process in comparison to a home environment. 3) **Form of the testing material –** materials tested in the form of smaller samples may perform differently when composted in their final product form. There is also some disparity between standard testing regimes, real-life studies and the actual practice conducted by home composters. The latter has not been studied in any great detail and yet studies and lab testing assume a 'well-managed' practice is being undertaken. Given that individual practices have a large bearing on the effectiveness of

composting, this is an assumption that will likely mean that at least some of the home compostable plastics will not perform as intended in real-life.

8.6 Recommendations to Reconcile Theory and Practice

Having analysed the differences between home composting and the current standards, three approaches are recommended for addressing discrepancies between existing frameworks and conditions to be found in practice:

- Further validation testing in home composting conditions
- Refine the wording of the draft CEN standard on home composting
- Develop clear communication with the consumer

Further Validation Testing in Home Composting Conditions

This research has identified that the actual ranges of abiotic conditions within home composting systems are wider that in test conditions.

As a way of strengthening the validity of the tests some products that currently pass existing tests could be subjected to further testing under less optimal conditions to see how this affects the biodegradation and disintegration processes. This would not need to be done for each product as part of the test standard, but would be a valuable validation exercise. See Table 23 for examples of where further testing may be warranted, although it is likely that temperature will have the biggest impact and therefore this parameter should be prioritised.

Additionally, the ADEME study revealed that even in a well-managed home compost pile it is possible that visually identifiable fragments of material are likely to be present in the compost after a year. Although it was established that this does not raise any ecotoxicity concerns, consumers need to be reassured that these fragments will continue to biodegrade once the compost is used on the soil. The study concludes:

> *"It also seems appropriate to warn individuals that the presence of pieces of bags at in the final compost is possible but that it does not affect the quality of the compost and that the materials will degrade in the soil at an undefined time scale." Translated from French*

"An undefined timescale" may not be acceptable and therefore verification of this should be undertaken to determine whether this is the case. There appears to be no particular merit in adding an additional test to the standards, but conducting further experiments on the remaining fragments to determine the fate once added to a soil environment would mean the assertion from the ADEME study could be validated.

Table 23: Potential areas of further testing to strengthen validity of certification

Testing conditions (Draft CEN drawing on ISO 14855)	Range in home composting studies identified	Satisfactory equivalence?
Temperature 25°C ±5°	Spring to Autumn ambient temperatures; most likely to be in the range of 10 - 20°C	Further testing advised
Duration 12 months for biodegradation	3-12 months	Yes
pH 7-8	pH range 5.9-9.28	Further testing advised
C/N ratio 10-40	C/N ratio 10-66	Further testing advised
Moisture maintained around 50%	Moisture values ranged from 22% to 85%	Further testing advised

Refine the Wording of the Draft CEN Standard on Home Composting

Another approach to ensuring the replicability of test results in the real world is to more clearly define the home composting system that should produce the same conditions as the test regime.

It is recommended that the CEN standard describes more clearly the add-as-you-go method with the management appropriate to maintaining a healthy compost pile, whilst making explicit that this is likely to be a ‘cold composting’ process. If the test results are valid in this context then the material should perform even better in a hot composting process.

Greater clarity would be welcomed in describing the conditions expected in the home compost system, and also clearly listing the management method needed to achieve this. This should include both a description of the range of abiotic conditions for which the test is deemed reliable (temperature, duration, pH, moisture), and related to this a set of practices which will ensure these conditions. It is also important to make the distinction between best practice and a minimal practice that can be undertaken to achieve an effective composting process.

National level guidance could then follow the wording of this standard and in this way greater consistency in practice may be achieved across different EU countries. Regional variations in practice should still be encouraged where they are adaptations to climate or cultural preferences. Promoting community compost schemes is another way of supporting the spread of best practice as the knowledge of composting is condensed in the community ‘master composters’ who can support each other in their knowledge development.

Clear Communication with the Consumer

However, if the testing and labelling is refined, there will be a need for effective communication with the consumer so that their expectations are in line with the applicability of the test.

Labelling should give the consumer an expectation of a time frame for the composting of the plastic material, which could be described relative to what they currently know of as a typical time frame in their own context. i.e. if in very cold climates it usually takes more than a full year for food waste to compost, this is also to be expected for plastic products labelled as compostable. Harmonising at the EU level would therefore be problematic.

Another area where clarity is needed is in distinguishing between traditional home composting practices and novel indoor composting practices that are increasingly called ‘composting’ but involve a very different biological process that is unlikely to biodegrade plastics. These include vermicomposting and Bokashi (fermentation).

Finally, for home composting labelling to function well it will need to be accompanied by a strong—possibly region specific—communication programme. Ultimately the responsibility for achieving this should not be the placed solely on the certification bodies, but in collaboration with other levels of government, in particular national and local.

8.6.1 Home Composting of Plastics as Part of the Circular Economy

Home composting as a means of treating domestically produced biowaste brings ecological benefit because it eliminates related GHG emissions from fuel used to run vehicles/machinery for collection and transport, thus also bringing economic benefit of saved collection and transport costs of the waste. It also offers a means of improving soil quality without the need for chemicals (for those that have gardens), and at the same time encourages local responsibility for waste. Home composting of plastics will only marginally add to this potential benefit through avoiding transport costs and the associated reduction in GHG emissions. It will however bring a range of complications to the process, at least initially as consumers have to learn how to process this new category of waste. There also appears to be no evidence to suggest that the material itself provides any specific benefits to the home compost.

Perhaps the relatively small benefit from labelling more products as home compostable could be increased if this is accompanied by a greater promotion of home composting through education and support to those wishing to learn how to manage their compost but there is a relatively high likelihood that this will not reach all the relevant households and it cannot be taken for granted that this approach will be applied in a homogenous way across cities, regions and countries. This is problematic if one considers that once on the market such products can be sold widely. This may be problematic given the difficulties in monitoring home composting in terms of practice, quantities of waste processed and outputs. Furthermore, measuring the input of the home composting process in line with the measurement method required to calculate recycling of other packaging would likely be almost impossible. Community scale composting is however a more viable option as a local waste management tool.

Table 24 shows how home composting can be viewed differently in the context of criteria setting for beneficial use. Fewer criteria are needed as the emphasis changes to what most benefits the householder. For example, increasing the capture of biowaste is not an imperative for the householder (they have no targets to meet); although from a public policy perspective it is still important to divert organic matter from residual waste streams. However, as separate collection is implemented over the next three years, this will be less of an issue and the focus should be on which applications there is justification for home compostable plastics over industrially compostable plastics.

What is also important, is that householders do not accidentally put conventional or industrially compostable plastic in a home composter through confusion. Arguably this confusion only exists because of compostable plastics—very few home composters would knowingly put conventional plastic in their pile and they would soon see the consequences of their mistake. Because of this, the applications are considerably narrowed, so as to avoid this confusion. In this case only biowaste bags, fruit labels and tea bags are recommended—the latter two are likely to end up in home composting anyway, and it is only recently that public attention has been drawn towards the somewhat disguised plastic content of teabags. Compostable coffee pods are only recommended if no other material alternatives are available on the market.

With regard to the prerequisites identified in Section 7.2 for industrial composting, the requirement for infrastructure is not necessary (although home composters will obviously need a compost pile set up), however the following would still apply:

1) Products in their entirety must meet EN or local Standards for composting of packaging or plastic products – i.e. compostable products should not be comprised of components that do not meet the standards
2) The term 'biodegradable' is not used on the product or any marketing communication associated with it.
3) The correct waste management route is clearly identifiable for the end consumer/user and this is communicated effectively on the product/ packaging

It is also likely given the performance of plastic films in testing, that all of the rigid packaging in the example products list would not pass the relevant testing especially if it is made from PLA. Reusing carrier bags or vegetable bags as caddy liners for collecting biowaste for home composting may be a viable option, but there is still a danger of confusion leading to PE bags being used. Clear messaging may negate this somewhat, and bags have a large area to provide the appropriate messaging. Unfortunately, the increased use of industrially compostable bags creates another layer of confusion.

As previously identified (Section 5.1), the French approach to this is to make sure all compostable products are also home compostable, therefore the consumer does not need to make this distinction. There is some merit in the approach of reducing complexity although it may result in some unintended consequences; as identified, some materials such as PLA are inherently unsuitable for home composting and are therefore unlikely to pass the French Standard for this. Many materials that do pass home composting tests use thinner gauges than for industrial composting – this could restrict applications that may require thicker material for functionality. Similarly, rigid products (bottles, etc.) are also unlikely to be pass the test although this study has already shown that rigid plastic products are mostly unsuitable as an application of compostable plastics. As this amendment has only just been passed, the exact implications are not yet known, however.

Table 24: Criteria Testing for Home Compostable Plastics (5= completely true, 1= completely untrue, lowest weighted score possible = 12, highest = 60)

Example products	Not recyclable or could not have been designed for reuse	Reduces the contamination of compost with non-compostable plastics	Does not lead to increasing contamination (consumer confusion)	Wtd Score	% of Max Score
Weighting>>	3	4	5		
Carrier bags used in supermarkets	2	2	2	24	25%
Biowaste bags as liners for indoor caddy	5	3	4	47	73%
Clothing packaging bags e.g. for shirts	2	1	1	15	6%
Pre-packed fresh fruit bags	3	2	2	27	31%
Trays used for fast food	2	1	1	15	6%
Rigid Fast food Containers	2	1	1	15	6%
Single use paper cups with plastic liner	2	1	1	15	6%
Supermarket vegetable bags	4	2	2	30	38%
Coffee capsules/pods	2	1	1	15	6%
Coffee capsules/pods (alternatives banned)	2	3	5	43	65%
Benchmarks					
Single Use Bottle	1	1	1	12	0%
Fruit Labels	5	5	3	50	79%
Tea Bags	5	5	3	50	79%

8.6.2 Key Conclusions

Key Conclusions – Recommendations to reconcile theory and practice

Reconciling theory and practice matters for two reasons. Firstly, a consumer who puts a plastic product labelled as suitable for home composting will expect to see that product disappear into the compost at the same speed as the rest of the material. If there is a clear discrepancy here then the trust in the labelling process will be undermined.

Secondly, any loophole in the testing procedure opens the way for exploitation of the labelling process by manufacturers who seek to bring to the market new products as compostable without concern for the end result.

This report makes three recommendations for approaches to address the discrepancies between existing frameworks and conditions to be found in practice.

1. **Further Validation Testing in Home Composting Conditions**

As a way of strengthening the validity of the tests some products that currently pass existing tests may need to be further tested under less optimal conditions to see how this affects the biodegradation and disintegration processes. This would not need to be done for each product but would be a valuable validation exercise and may lead to changes in the testing regime for associated Standards.

IN the same way, that residual microplastics are a concern in industrial composting the same is true for home composting. Additional testing of materials using soil as an inoculum would ensure that were compost to be used with fragments of plastic material remaining, consumers could be confident that the fragments would continue to biodegrade once used on the soil.

2. **Refine the wording of the draft CEN standard on home composting**

This report recommends that the CEN standard describes more clearly the add-as-you-go method whilst making explicit that this is likely to be a 'cold composting' process.

This should include both a description of the range of abiotic conditions for which the test is deemed reliable (temperature, duration, pH, moisture), and related to this a set of practices which will ensure these conditions.

3. **Clearer communication with the consumer**

Inevitably, however the testing and labelling is refined, there will be a need for effective communication with the consumer so that their expectations are in line with the applicability of the test and the quality of the compost is not undermined.

- Labelling should give the consumer an expectation of a time frame for the composting of the plastic material, which could be described relative to what they currently know of as a typical time frame in their own context. i.e. if in very cold climates it usually takes more than a full year for food waste to compost, this is also to be expected for plastic products labelled as compostable.
- It should be made clear that novel indoor composting practices are not suitable for the treatment of 'compostable' plastics.
- Finally, for home composting labelling to function well it will need to be accompanied by a strong—possibly region specific—communication programme. Ultimately the responsibility for achieving this should not be placed solely on the certification bodies, but in collaboration with other levels of government, in particular national and local.

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Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy - APPENDICES

For the European Commission DG Environment. Project conducted under Framework Contract No ENV.B.3/FRA/2017/005

March – 2020

Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy

Appendices

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APPENDICES

A.1.0 Biodegradable Plastics Market Additional Information

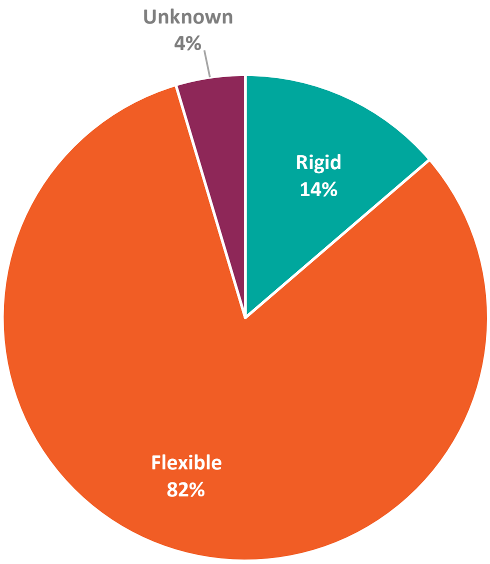
A.1.1 Types of Certified Product

It was found that TUV Austria certify approximately 1,400 products[1], and DIN Certco have certified products for around 300 companies[2]. Due to the better granularity of the data available, the following section looks at products certified by TUV Austria; by end product type. As TUV Austria hold a significantly larger market share of biodegradable certifications, it is expected that this is representative of the certified market as a whole—this also provides an indication of the overall share of the market for each product group as one would expect that more certifications would be present for products that have a larger market share as these markets present greater opportunities. It should be noted that TUV Austria currently certify 995 (69%) products for industrial composting, 442 (30%) for home composting, 13 for soil biodegradability, 1 for fresh water biodegradability and none for marine biodegradability (although it certifies 17 raw materials). Of the thirteen soil biodegradable products, ten are agricultural mulch films and the other three are unknown packaging or miscellaneous. Of the bags for the collection of organic waste, 36% are certified as home compostable. Of the certified shopping bags, 32% are certified as home compostable.

[1] *TUV Austria: Certified Products*, accessed 25 June 2019, http://www.tuv-at.be/certified-products/

[2] *DIN CERTCO - Companies with certified / registered products for 'Products made of compostable materials'*, accessed 25 June 2019, https://www.dincertco.tuv.com/search/companies_with_product?locale=en&starting_letters=A&title_id=85

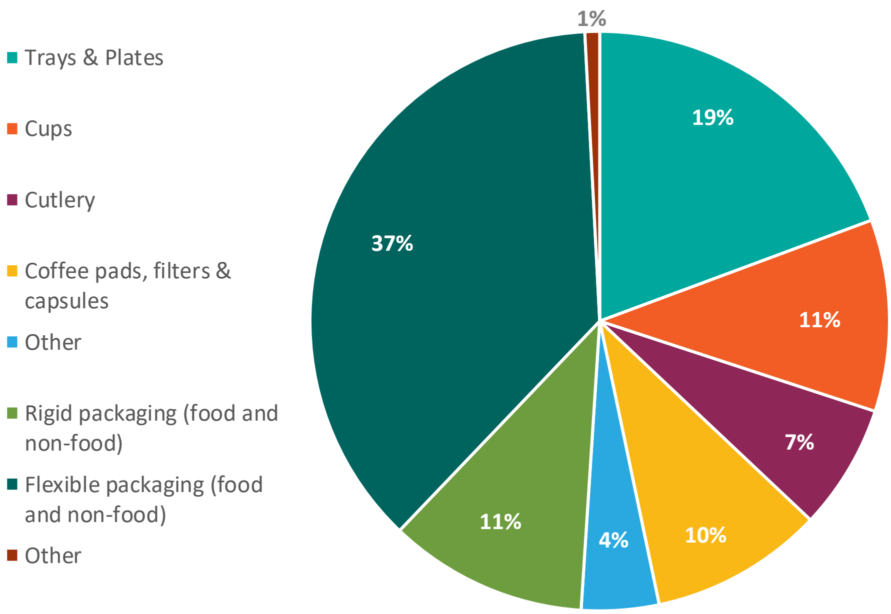
Figure 1: Share of TUV Austria certifications that are for flexible or rigid products



As shown in Figure 1, 82% of products certifications are for flexible plastic, with 14% rigid plastic and the remaining 4% unknown.

Figure 2 shows the share of TUV Austria certifications within catering and packaging by end product type (the two largest sectors after bags). This gives an indication of the number of certified products on the market. As shown, flexible packaging takes a large proportion of this, at 37%.

Figure 2: Share of TUV Austria certifications for catering and packaging, by end product type



A.1.2 Size of the European Market until 2029 - BAU

A.1.2.1 Method

Modelling has been undertaken to estimate the quantity of biodegradable plastics on the market within Europe. The data available for this modelling is very limited, as it is a relatively new research area. Assumptions have been made to make the modelling possible; limitations of the analysis are discussed in section A.1.2.3.

The model uses the global market value in 2016, the growth rate between 2017 and 2018 as reported by European Bioplastics[3] and the European market share in 2016 to see how the market value in Europe until 2029 could look in a business as usual (BAU) scenario assuming no specific changes to the current policy framework. This scenario is therefore not necessarily a prediction of how the market is likely to look in the future.

- The global market value in 2015 was reported to be $2.1 billion[4];
- Growth at 3.05% (as between 2017 and 2018); and
- The European market share in 2016 was reported to be 35-40%[5].

Key assumptions were as follows:

1) The compound annual growth rate (CAGR) value remains constant between 2014 and 2029; and
2) Europe consistently holds 35-40% of the market over the aforementioned period.

A.1.2.2 Results - BAU

A scenario for the value and size of the biodegradable plastics market until 2029 is as shown in Figure 3. As shown, this analysis demonstrates that the European market could reach a value of roughly €1 billion by 2029 in a BAU scenario. This would have significant implications for the bio-economy in Europe. In this BAU scenario, it is calculated that the quantity of scope biodegradable plastics on the market could reach over 360 ktonnes by 2029; almost twice what is currently on the market from the estimates made for this study. It is clear that there are also many additional variables that will affect the market and therefore, this scenario should not be considered a forecast of the likely market.

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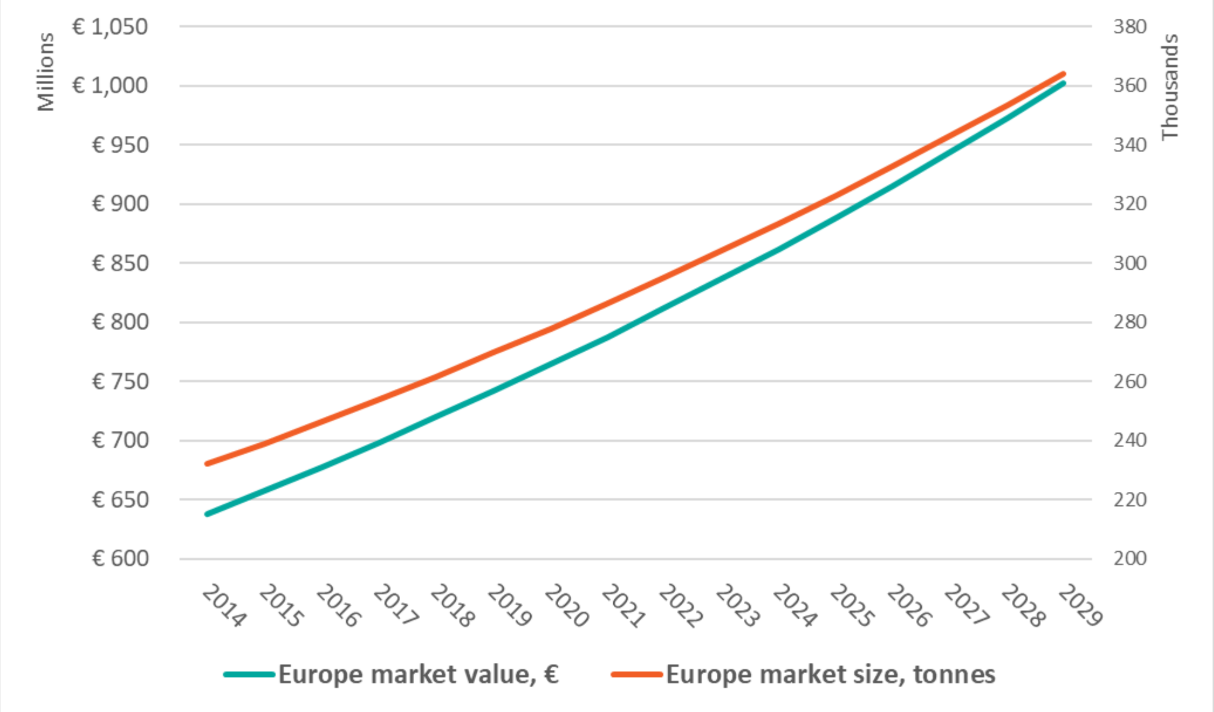
[3] European Bioplastics (2018) Bioplastics Facts and Figures 2018
[4] *Biodegradable plastics - Global Market Outlook (2016-2022)*, accessed 17 May 2019, https://www.strategymrc.com/report/biodegradable-plastics-market
[5] *Biodegradable plastics - Global Market Outlook (2016-2022)*, accessed 17 May 2019, https://www.strategymrc.com/report/biodegradable-plastics-market

Figure 3: Value and Size of the Biodegradable Plastics Market in Europe, 2014 to 2029



A.1.2.3 Limitations

This analysis shows enormous growth to 2029 in the business as usual scenario; a result that should be treated with caution. Although this scenario is based on the data available, this result has many limitations and is not necessarily a prediction of how the market will look in the future.

The assumption that Europe consistently holds 35-40% of the market over this period is unlikely to be the case, as it has been said that the European market is seeing the most growth for biodegradable plastics.[6] As this relative growth has not been quantified, it is difficult to project how this may influence absolute quantities on the European market.

It has also been assumed that the growth of the biodegradable plastics production capacity increases at a rate of 3%. This figure is based on the change in production between 2017 and 2018, and although it has been confirmed by stakeholders, it is not definitely representative of the growth of the market as a whole. It is a very limited data period to use to project for the following ten years, and there are bound to be fluctuations in the market.

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[6] European Bioplastics (2018) Bioplastics Facts and Figures 2018

The biodegradable plastic production capacity figure used as a starting point for the analysis is based on data that is largely variable, as outlined previously the market is extremely difficult to trace due to the relative size of businesses consuming these biodegradable end products.

Finally, it is also important to recognise that there are various unpredictable market drivers that may have a huge negative or positive effect as outlined in the main report.

A.2.0 Coverage Assessment of Product Labelling Analysis

The sample by country is shown in Table 1. The labelling assessment is skewed slightly towards German products; however, this was not deemed to affect the results – German products did not seem to show particularly good or bad practice in comparison to products from other nations.

The sample by market segment is shown in Table 2. As shown, a large sample of carrier bags was assessed, however only a small sample of organic waste bags.

Table 1: Sample for labelling assessment by country

Country	No. in sample
UK	10%
Italy	21%
Germany	28%
France	14%
Expected on whole European market	28%
Other	0%

Table 2: Sample for labelling assessment by market segment

Market segment	No. in sample
Packaging	31
Carrier bags	15
Organic waste bags	3
Other	13
Agriculture and horticulture	0
Consumer goods	3
Other	0

A.3.0 Compost Quality

Table 3: Compost Physical contaminants: maximum allowable concentrations in various EU Countries (only thresholds that may concern plastics are reported)

Country	Impurities	Mesh size	Limit values (w/w % dry matter)
Austria	Total (agriculture) (land reclamation) (technical use) Plastics (agriculture) (land reclamation) (technical use)		 <0.5% <1% <2% <0.2% <0.4% <1%
Belgium	Total	>2mm	<0.5%
Czech Republic	Total		<2%
Germany	Glass + plastics + metals		<0.5%
Spain	Total		<3%
France	Plastic films	>5mm	<0.3%
Ireland	Total		<0.5%
Italy	Glass + plastics + metals		<0.5%
Netherlands	Total		<0.5%
Denmark	Total Plastics	>2mm	<0.5% <0.15%
United Kingdom	Total (herein included plastics)		<0.5% <0.25%
EU Fertilisers Regulation	Glass + plastics + metals (any of the foregoing)		<0.5% <0.3%

Source: JRC

A.4.0 Criteria Development

A.4.1 Criteria Taken forward

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Further evidence/research
Effective organic waste collection, sorting and treatment infrastructure in place that accepts compostable plastic	FEAD, Syctom, German waste associations, Suez	Composters/AD operators have identified issues such as the materials not fully biodegrading and compostable plastics being incompatible with machinery	Yes – Effective biodegradation can be assessed through compositional studies in composting plants, but at a practical level, if the process does not reflect the conditions set out in EN 13432 it is likely to be problematic.	Mixed – some countries (Italy) have studied this more than others, but evidence is mostly anecdotal. It is clear that many countries use an AD process with no secondary composting stage which makes full biodegradation challenging.	Determining whether it is beneficial to change/improve infrastructure to better accept compostable plastics and how this can be financed (potentially through EPR)

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Further evidence/research
The product in its entirety must meet EN Standards for composting of packaging or plastic products	FEAD	The requirement to meet appropriate EN (or country equivalent) standards for composting in an industrial setting. The standard includes requirement that the entire product designed to be compostable material.	Yes – the standard(s) require specific tests with a pass/fail criteria	Yes – the requirement for a test to verify performance is undisputed. The nature of these tests is sometimes questioned.	There is some merit in addressing the discrepancy between the standards and the typical practice to make them more representative
The correct waste management route is clearly identifiable for the consumer/user	FEAD, Syctom	Packaging displays clear and unambiguous instructions that allow the householder to dispose of correctly in the	Challenging – currently this message will be different between countries and within countries	No – there are no significant and well documented and successful trials. Current information is often mixed in its message. Labelling schemes associated with composting test standards are generic and non-instructive	This needs to be approached in tandem with the waste management system. Determining the extent to which information can be generic will be important.
The term 'biodegradable' should not be used	German waste associations, Suez	Identifies that the term is confusing for consumers and may lead to littering or other incorrect disposal.	Yes – terminology can be defined and set as a requirement.	Limited – evidence for consumer behaviour in response to terminology is lacking. Nevertheless, it is clear that current ambiguity will lead to confusion.	Research into consumer expectations in relation to terminology may help to strengthen labelling and communication.

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Further evidence/research
Compostable plastic should not be mixed with other non-compostable materials	Project team	Products containing compostable material should not contain any non-compostable material especially if it cannot be separated – this is already a prerequisite of EN 13432	Yes – this can be a defined rule to back up EN 13432 unless the standard is mandatory.	Yes - Although this is a requirement in EN 13432 it is important enough to highlight on its own.	None
If the use of compostable plastic reduces non-biodegradable plastics in organic waste collection	EUBP	The effect of compostable plastics reducing contamination in compost from conventional plastic.	Challenging – Compositional studies in composting plants can be used, but isolating cause and effect is difficult.	Limited – evidence base is built on biowaste bags with no other examples of other products having the effect.	Identify and verify examples beyond biowaste bags where this effect also occurs
If there is a low likelihood of item being effectively recycled (recycling prioritised over composting)	EUBP, FEAD	The notion that recycling (mechanical, chemical) is more beneficial and better reflects the principles of circular economy than composting of plastics	Challenging – this links to ongoing work on defining and measuring what can be considered 'recyclable'	Mixed – LCA results suggest that recycling is beneficial, but assumptions around the benefit gained from recycling are often exaggerated	Whilst virgin material replacement recycling can be considered circular, other less beneficial applications (downcycling) may be similar to composting. Determining the cut-off point will be important.

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Further evidence/research
No reusable solutions available	EUBP	A focus on the waste hierarchy where reuse should be prioritised.	Challenging – there are reusable solutions for almost all products	Yes – Evidence for reuse is strong and a key tenet of EU waste policy	Products could be identified on a case-by-case basis using LCA to determine the best option
Bring 'environmental benefits'	FEAD	The concept that the net environmental impact is beneficial	Yes – through the use of LCA this can be achieved, but the study should use system expansion and/or appropriate function unit to account for the full life cycle including any 'co-benefits'	Mixed – many products appear on the market without the requirement for and LCA in order to exist. This requirement should not just be for compostable plastic.	Investigate incorporating this into the 'Essential Requirements' in order to subject all packaging to this criterion.

Table 4: Rejected Criteria

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Reason for Removal
Compostable plastics are at least partly made from renewable materials	German waste associations	The proposition that bio-based plastic can be the best environmental option depending upon the lifecycle of the product	Yes – there are several methods/labels for verifying this.	Mixed – making plastic from biomass is not always preferable and not a prerequisite for being compostable. Conventional plastic also does not have this requirement imposed.	The original proposition can be best incorporated into a criterion ensuring 'environmental benefit'

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Reason for Removal
Use only in packaging which are 'rapidly consumed'	Sytcom	Possibility of specifying material which biodegrades in a shorter timeframe as it does not require a long shelf-life	Challenging – defining a limit for 'rapidly consumed' may be difficult	Poor - The conditions for composting (biodegradation) do not generally exist on a shop shelf, therefore the premise of this criterion may be flawed	Irrelevant is the product already meets EN13432 and the composting process is sufficient.
Absence of suitable/available 'natural' compostable materials	Project team	The premise that other natural material such as paper avoids some of the problems associated with compostable plastic (e.g. will fully biodegrade, not leave microplastic residue and does not confuse consumers)	Challenging –defining whether an alternative is 'suitable' will be open to interpretation unless specific product groups are highlighted.	Mixed – evidence from LCA is often contradictory with regard to the (GHG) impacts of paper compared with alternatives. There is no evidence that newspaper is problematic (toxic) in composting.	Adopting a material neutral approach
If compostable and non-compostable plastics exists within the same product group	Sytcom	In order to reduce consumer confusion and the potential to normalise putting plastics in organic collection.	Yes – product groups can be identified and defined	Mixed – mostly anecdotal, but also it is logical to assume identical products that require different waste streams will cause confusion	Will be combined with – "If the use of compostable plastic reduces non-biodegradable plastics in organic waste collection"

Criterion	Proposed by	Detail/Premise	Can it be measured/ defined accurately?	Is the current Evidence Robust?	Reason for Removal
Compostable material is not used in products that contain or come into contact with human or animal waste	Project team	These sorts of contaminants need specialised collection and facilities to process – high volumes in conventional composting may be problematic.	Yes – products can be well defined and categorised	Yes – products such as nappies are already used in high volumes that could significantly change the nature of composting and affect compost quality (not meet standards)	This can be covered by other criteria focusing on not having detrimental effects in composting.
The product is contaminated with food	EUBP	Food contamination increases likelihood that the consumer will dispose of it in organic waste and reduced ability to (mechanically) recycle the material.	Challenging – defining the cut-off point where a certain level of contamination will mean that one material is more suitable than another is difficult.	Mixed – as above the link between food contamination and plastic items being placed in organic waste is not fully established	Integrated with other criteria
'Semi-rigid' compostable plastics are only suitable for 'closed' systems	EUBP	In this context a 'closed' system is defined as application in catering where the material is collected and processed separately. Rigid or 'semi-rigid' compostable plastics will break down slower and also may be confusing for consumers therefore commercial applications are potentially more suitable.	Yes – products can be well defined and categorised	Yes – closed systems have been demonstrated to work as a partnership is formed with the waste operator.	Integrated with other criteria

A.5.0 Home Composting Additional Information

A.5.1 Conditions Found in Home Composting

A.5.1.1 Temperature

Temperature in the home composting system is a key variable with regard to the biodegradation of plastics and it is important to understand the relationship between the temperature in a compost pile and the ambient temperature.

The studies analysed have assessed home composting within a range of climatic conditions with ambient temperatures ranging from -15°C [7] to 36°C [8]. Across the studies it is reported that compost temperatures remain consistently higher than ambient temperature by few degrees (2-10°C). Figure 4 shows the temperature profile for a home composting system that was fed for an initial period of two weeks and then left. It can be seen that the temperature in the compost follows ambient temperature closely, but in the initial feed stage higher composting temperatures are reached as microbial activity intensifies. A similar temperature profile is seen in the ADEME study series 1, with the temperatures in the compost pile rising significantly above the ambient temperature for the first 3 months, then following ambient levels. (See Figure 5) This is the result of the intense microbial activity in this early stage which occurs despite the low ambient temperatures of below 5ºC which were present at the beginning of the study. The temperature profile also shows that after that initial peak of microbial activity the compost pile temperature reduces and begins to closely track the ambient temperature after around month three as the compost matures.

In four of the eight studies analysed, cold composting is in evidence with temperatures not reaching the 45°C needed for the thermophilic phase. Four of the studies, including the ADEME study, reported peak temperatures in excess of 55°C but it is not clear if these temperatures were sustained for long enough to allow for a thermophilic phase. The low peak temperatures do not seem to have affected the quality of the compost as measured in these studies.

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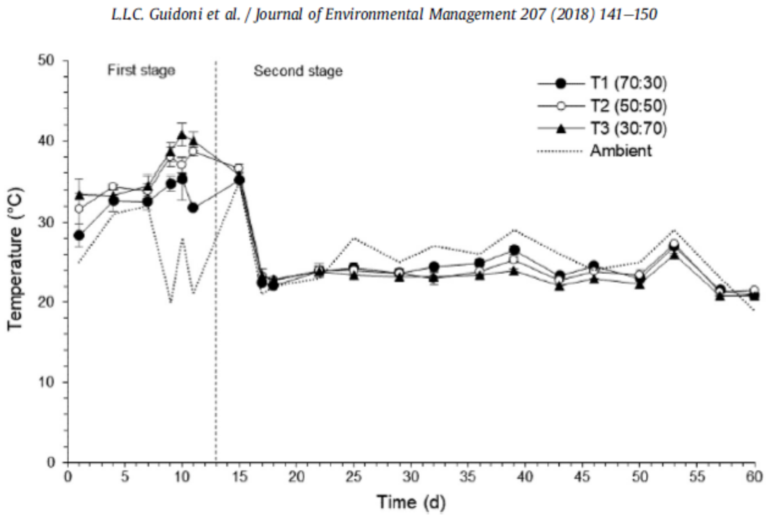
[7] Ermolaev, E., Sundberg, C., Pell, M., and Jönsson, H. (2014) Greenhouse gas emissions from home composting in practice, *Bioresource Technology*, Vol.151, pp.174–182

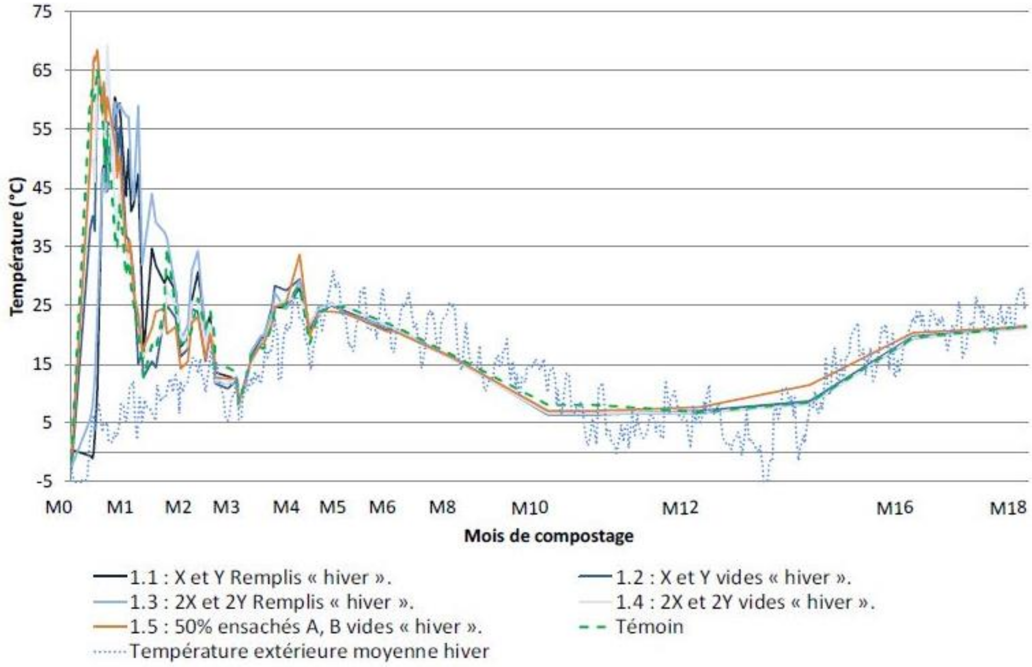
[8] Guidoni, L.L.C., Marques, R.V., Moncks, R.B., Botelho, F.T., da Paz, M.F., Corrêa, L.B., and Corrêa, É.K. (2018) Home composting using different ratios of bulking agent to food waste, *Journal of Environmental Management*, Vol.207, pp.141–150

Figure 4: Home composting temperature profile - relation to ambient temperatures



Source: Guidoni 2018

Figure 5: Temperature profile of home composting in ADEME 2019 study

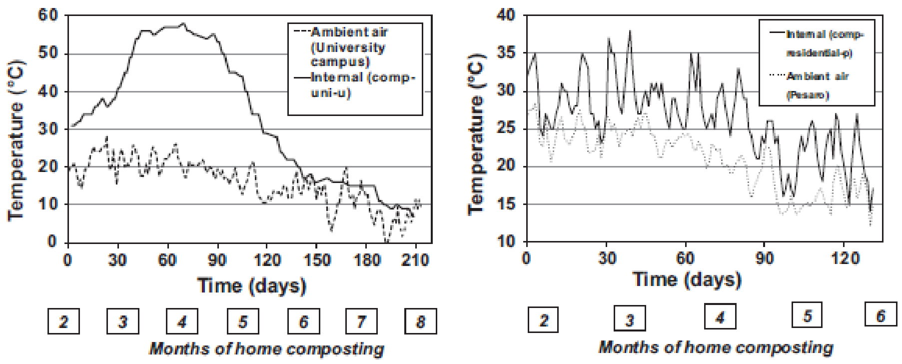


Source: DeWolfs et al (ADEME) 2019

The studies found that larger feeding loads and more frequent feeding raised the peak temperatures attained. [9] This would indicate that changes in composting practice can be used to balance the differences in ambient temperature across different regions, suggesting that even with the extremes of climatic conditions found in Europe home composting is a viable means for dealing with organic waste.

Figure 6 shows a comparison between the temperature profile of a compost system kept outdoors on a university campus fed according to a regular regime, with a home composting system serving a multi-occupancy house in Italy with an irregular feeding regime. [10] The regularly fed pile (left image in figure) shows a classic temperature pattern, with a well-defined thermophilic phase, with temperatures above 45°C for 60 days. A much more varied profile is evident in the irregularly fed pile, illustrating the practice of 'cold composting' with temperatures closely following ambient temperatures and the peak temperature only briefly reaching 37°C. However, this pile still maintains a temperature sufficient to allow mesophilic microbial activity (>20°C) for the majority of the time.

Figure 6: Home composting temperature profiles showing variability



Source: Tatano et al. 2015

- **Temperature range recorded within compost pile across all studies ranged from 5-70°C**
- **Only 4 out of 8 studies showed temperatures reaching above 45°C – necessary for thermophilic bacteria to thrive.**

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[9] Guidoni, L.L.C., Marques, R.V., Moncks, R.B., Botelho, F.T., da Paz, M.F., Corrêa, L.B., and Corrêa, É.K. (2018) Home composting using different ratios of bulking agent to food waste, *Journal of Environmental Management*, Vol.207, pp.141–150

[10] Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E., and Mangani, F. (2015) Biowaste home composting: Experimental process monitoring and quality control, *Waste Management*, Vol.38, pp.72–85

A.5.2 Moisture

Compost needs to remain moist but not overly so. Excessive moisture content can inhibit activity of microbes as it can reduce air-filled pores limiting the flow of oxygen that microbes depend on. It can also impede the necessary temperature development.[11,12] Equally problematic is a lack of moisture as the microbes will die or go dormant if the compost dries out too much. There is little evidence for what the microbial tolerance limits are with regard to moisture.

Tatano et al studied the moisture profile of four different home composting practices in Italy. The study found a gradual decline of moisture which was indicative of the progress of the composting practice.[13] The starting moisture content differed between practices, but followed a similar decline; the authors offer no reason for the observed differences between practices.

- **Most of the studies did not record the moisture levels during the composting process, recording only the final moisture content.**
- **This ranged from between 22% to 85%.**

A.5.3 Ratio of Carbon to Nitrogen

C/N values are determined by the balance of green and brown input materials and decline over time as the nitrogen becomes concentrated in the compost. It is difficult for a home composter to assess these levels but a foul smell will indicate an imbalance.

The balance of Carbon to Nitrogen affects the rate of decomposition as the microorganisms require the correct proportion of carbon for energy and nitrogen for protein production. If there is too much carbon the composting rate will slow and if there is too much nitrogen it will be released in the form of ammonia (NH_3) – which has a distinctive smell and is an indicator of the mix being incorrect. A C:N ratio of 25-30:1 is deemed ideal,[14] with higher values potentially slowing down the rate of decomposition.

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[11] Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E., and Mangani, F. (2015) Biowaste home composting: Experimental process monitoring and quality control, *Waste Management*, Vol.38, pp.72–85

[12] Guidoni, L.L.C., Marques, R.V., Moncks, R.B., Botelho, F.T., da Paz, M.F., Corrêa, L.B., and Corrêa, É.K. (2018) Home composting using different ratios of bulking agent to food waste, *Journal of Environmental Management*, Vol.207, pp.141–150

[13] Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E., and Mangani, F. (2015) Biowaste home composting: Experimental process monitoring and quality control, *Waste Management*, Vol.38, pp.72–85

[14] Home Composting Made Easy *The Carbon/Nitrogen Ratio*, accessed 26 June 2019, http://www.homecompostingmadeeasy.com/carbonnitrogenratio.html

- **Across the studies surveyed C:N ratios ranged from 10:1 to 66:1, though only three studies reported on this directly.**

A.5.4 pH value

The pH level of compost changes as composting proceeds as the organic acids produced in early stages become neutralised as the compost matures. Compost organisms can grow and multiply within the pH range of 5.5 to 8, [15] Tatano et al tested the pH profile of 4 home composting conditions using commercial compost standards as the guides to pH range. Only one treatment condition showed pH values above 8, indicating that for most of the conditions, pH levels were within the bounds of acceptability.[16]

- **The final pH levels across these studies ranged from 5.9 to 9.28**

[15] *pH measurement of compost*, accessed 28 June 2019, http://www.carryoncomposting.com/416920214

[16] Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E., and Mangani, F. (2015) Biowaste home composting: Experimental process monitoring and quality control, *Waste Management*, Vol.38, pp.72–85

Table 5: Composting conditions recorded in reviewed studies

Author, date	Country	Study focus	Container capacity	Feed materials	Weekly weight of feed	Ratio of green to brown	Mixing frequency	Ambient temperature range	Temperature range in compost	final C:N ratio	final pH	final moisture content	Time period
Andersen, 2011	Denmark	greenhouse gas emissions from home compost	320L	kitchen waste, no meat or dairy some garden waste	2.6-3.5kg	23:1	no mixing/every week/ every 5 weeks	0-20°C	peaked at 27°C Cold composting	15-17:1	not reported	not reported	1 year
Arigoni, 2018	Argentina	layering effects in cold climate	500L	kitchen and green waste and pine shavings	45kg	1.5:1	no	0-15°C	5-70°C	no data	6.5-8.8	no data	8 months
Ermolaev, 2014	Sweden	greenhouse gas emissions from home compost	115L to 345L	83% food waste	1.61kg to 4.97kg (seasonal variation)	4:1	range from none to every 5 days	-15°C -29°C	on average 8°C degrees above ambient Cold composting	not reported	7.20	28% to 85%	1 year
Guidoni, 2018	Brazil	green to brown ratios	50L	food waste and rice husks	4kg / 4.6kg and 5.1 kg	30:70, 50:50 and 70:30	no data	20-36°C	20-40.5°C Cold composting	66:1	8.21 - 9.28	43% to 68%	60 days

Klauss, 2004	Germany	different containers	500L	organic waste	Varied	no data	no	12-15°C	peaked at 55°C	not reported	"neutral"	22% to 67%	12 months
Lleo, 2013	Spain	home composting and vermicomposting	300L	Kitchen waste and garden waste	6.8kg	2.47:1	mixing when feeding	5-30°C	peaked at 55°C	not reported	5.90 - 8.97	50.3%	7 months
Tatano , 2015	Italy	in-situ home compost and simulated home compost	300L	Kitchen waste and garden waste	5.5kg	no data	no data	0-28°C	8-58°C	averages not reported.	averages not reported.	averages not reported.	7-13 months
Vazquez, 2017	Spain	efficiency of home composting	340L and 350L	food waste including meat and fish leftovers	no data	no data	no data	no data	7-35°C Cold composting	10 to15:1	no data	68.1%	1 year

A.5.5 Home Composting Supplemental Tables

Table 6: Comparison of national composting advice

Country	Organisation providing info	Description of Organisation	Compost method	Site	Size of container	Green and Brown ratio	Meat and fish?	Turning?	How to regulate moisture
BEL	Brussels Environment	Government Body	Multi container method	Easy access, semi-shaded, flat	multi container or 200L	50:50	No	Once or twice a week	water as needed
ESP	Zero Waste Europe	NGO. No national level organisation.	Multi container method - for community composting	close to residents	4 modules to allow maturation phase plus storage of bulking agent	no specification, monitoring moisture levels is key	Yes, inclusion is a benefit	essential	squeeze test
FIN	Päijät-Häme Waste Management Ltd (PHJ)	Waste Management company	Unclear	Semi shaded, flat, easy to get to	200L with insulation	70:30	Yes	not needed	water frequently
FRA	ADEME and Reseau compost citoyen.	National Government Body	Unclear	Semi-shaded, flat and drained	400L	70:30 in shared composter 50:50	Yes	Yes	squeeze test
UK	WRAP	National Government Body	Unclear	on soil	200-300L	50:50	No	Not essential but recommended if having issues	squeeze test, adjust by adding more greens

PRT	Lisbon city chamber	City Authorities	Describes batch compost method	Semi-shaded, water source nearby	no mention but image of 200L bin	50:50	no	Not mentioned	squeeze test

Table 7: ISO tests for biodegradation of plastic materials

Test number	Title	Description and key features
ISO 14851	Determination of the ultimate aerobic biodegradability of plastic material in an aqueous medium - Method by measuring the oxygen demand in a closed respirometer	Testing is done in aqueous medium Biodegradation measured by consumption of Oxygen 2 months duration
ISO 14852	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium - Method by analysis of evolved carbon dioxide	Testing is done in aqueous medium 2 months duration Biodegradation measured by analysis of evolved carbon dioxide
ISO 14855-1	Determination of the ultimate aerobic biodegradability and disintegration of plastic material under controlled composting conditions - Method by analysis of evolved carbon dioxide	Testing using a compost inoculum 6 months max, 58°±2°C, pH 7.0-8.0, C/N 10-40 Biodegradation measured by conversion of carbon
ISO 14855-2	as above - Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test (ISO 14855-2)	As for 14855-1 but with different way of measuring conversion of carbon
ISO 17556	Determination of the ultimate aerobic biodegradability in soil by measuring the oxygen demand	Testing using a soil inoculum 6 months max, 20-28°C Biodegradation measured by consumption of Oxygen

Table 8: ISO tests for disintegration of plastic materials

Test number	Title	Description and key features
ISO 16929	Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test"	Materials tested in 5x5cm or 10x10cm pieces in pilot scale composting using biowaste mixture Temp can rise to 65°C naturally, 12 weeks duration, C/N 20-30, pH >5 Sample then sieved through 10mm and 2mm sieve
ISO 20200: 2015	Plastics - Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test"	Qualitative assessment of disintegration 58 ±2°C for max 90 days, if not sufficient, then continue at room temp for max 90 days

Table 9: Summary of studies testing plastic biodegradation in home composting

Author, date	Materials tested	Country	Duration of study	Reported Biodegradation
Dewolfs et al 2019 (ADEME)	Bag X – 90% PBAT, 9% PLA, 1% green dye Bag Y – 70% PBAT, 30% starch	France	18 months	Visual inspection of biodegradation using TEM. The bag containing 9% PLA (bag X) showed a lower biodegradation than bag Y
Adamcova et al, 2016	HDPE mixed with TDPA additive/ PE and d2W additive	Czech Republic	12 weeks	HDPE + TDPA – 0% PE + d2w – 0%
Klauss, 2004	Starch based FARD bags Starch based TPSS trays Mater-BI Bioplast GF 102/13 PLA	Germany	52 weeks	Starch based FARD bags – complete degradation in 120 days Starch based TPSS trays – 88-95% Mater-BI – 40-77% Bioplast GF 102/13 bags – 50-76% PLA - no measurable degradation
Mohee, 2008	Mater-BI /EPI	Mauritius	10 weeks	Mater-BI – 26.9% EPI – 0%
Rudnik and Briassoulis, 2011	PLA film	Greece	47 weeks	"Low degree of disintegration"
Song, 2009	PLA PP(A), PP(B), PP(B)+, starch/PP, Mater-Bi	UK	24 weeks	PLA, PP(A), PP(B), PP(B)+, starch/PP, Mater-Bi – all had negligible mass loss of < 5%
Vaverkova, 2014	9 plastic bag samples that are labelled as 'compostable'	Czech Republic	12 weeks	Visual evaluation of disintegration – no changes observable except for bag made from starch

A.6.0 Research and Knowledge Gaps

The following is a summary of the key knowledge gaps and potential research needs that have been identified throughout this study:

- Market data by product type and geographic region is generally outdated and would benefit from an update to determine where the perceived increase in interest in compostable plastics has resulted in market increases in recent years.
- Under the Fertiliser Regulation it is clear that fertiliser such contaminated with compostable plastics residues could be exported and used in other EU countries. The risk of this is not entirely clear for fertiliser from digestate as the Regulation stipulates several process types that are suitable (including an option of secondary maturation), but these are all focused on eliminating pathogens in the digestate and not on successful biodegradation of plastics. Further testing under each one of the processes identified in the regulation would be required to verify this.
- Changing compostable plastic Standards (EN 13432) to reflect all industrial composting and AD practises is impractical and therefore it is recommended that Member States conduct their own trials to determine whether the Standard is fit for the purpose of verifying that compostable plastics perform as required (noting that 'performance' is a relative term that will be dictated by the local process and compost quality requirements). This will help in determining whether they should accept compostable plastics or not in their biowaste treatment facilities and what changes need to be made to do so in the future (if desirable).
- Generally, Life Cycle Assessment (LCA) studies are inconclusive and often have conflicting results for both comparisons between different compostable materials and bio-based or fossil feedstocks. Methodologies for assessing the end of life for compostable plastics and the production impacts of bio-based plastics require further development to enable accurate and fair comparisons.
- As a way of strengthening the validity of the standard tests for home compostable plastics, some products that currently pass existing tests may need to be further tested under less optimal conditions to see how this affects the biodegradation and disintegration processes. This would not need to be done for each product, but would be a valuable validation exercise and may lead to changes in the testing regime for associated standards.
- In the same way that residual microplastics are a concern in industrial composting, the same is true for home composting. Additional testing of materials using soil as an inoculum would ensure that were compost to be used with fragments of plastic material remaining, consumers could be confident that the fragments would continue to biodegrade once used on the soil.

A.7.0 Stakeholder Engagement

Company	Method of engagement	Topics discussed
European Bioplastics	Workshop, interview, consistent engagement	• Applications and suitability of compostable plastics for applications • Most common applications on the market • Proportion of market that is certified • Past and current quantity of products on the global market • Market within Europe • Future quantity of products on the market • Requested images of labels from across European market
Nova Institute	Workshop, email discussions	• Applications and suitability of compostable plastics for applications • Most common applications on the market • Past and current quantity of products on the global market • Future quantity of product son the market
BBIA	Inter view	• Current market, incl. product types most commonly found on the market. • Future market for biodegradable and compostable plastics, incl. expected size, type of plastics (incl. innovations) and product types.
BASF	Interview, workshop	• Current market, incl. product types most commonly found on the market. • Future market for biodegradable and compostable plastics, incl. expected size, type of plastics (incl. innovations) and product types.

Novamont	Interview, workshop	• Current market, incl. product types most commonly found on the market. • Future market for biodegradable and compostable plastics, incl. expected size, type of plastics (incl. innovations) and product types. • Labelling and communication on products. • General discussion around certified vs non-certified products on the market.
Natureworks	Interview, workshop	• Current market, incl. product types most commonly found on the market. • Future market for biodegradable and compostable plastics, incl. expected size, type of plastics (incl. innovations) and product types.
Vegware	Interview	• Size of the market within Europe. • Most common applications. • Future market for biodegradable and compostable plastics, incl. expected size, type of plastics (incl. innovations) and product types. • Labelling and communication on products
Din Certco	Workshop, email discussions	• Discussion around number of products certified on the market, how certifications are audited and what happens with non-conformances (no numerical data obtained)
TUV Austria	Workshop, email discussions	• Discussion around number of products certified on the market, how certifications are audited and what happens with non-conformances (no numerical data obtained)
DUH Germany	Workshop, email discussions	• Requested images of labels from across European market
Marco Ricci ECN – European Compost Network	Interview, workshop	• Positions of EU Composting Industry on compostable plastics • Possible Concerns on quality of end products • Niche applications (“closed loops”) vs. widespread use

Morten Brøgger Kristensen AIKAN	Interview,	• Use of compostable bags in Copenhagen • Fate of compostable plastics after pretreatment • Influence on compost quality
Isabelle Deportes ADEME	Interview	• Trials on compostable plastics in home composting systems (not yet available) • Fate of compostable plastics during composting
Alberto Confalonieri CIC	Interview	• Effects on quality of end product • Acceptance of compostable plastics by site managers • Niche applications ("closed loops") vs. widespread use
Chaim Gabriel WaibelPRE	Interview	• Maximum acceptable levels of compostable plastics in various streams of polymers for mechanical recycling
Marco Alberti, Antonio Furiano COREPLA	Interview	• Interaction between operational schemes at sorting platforms and presence of compostable plastics in various polymers targeted for mechanical recycling • Effect of presence compostable plastics on mechanical recycling • Maximum acceptable levels of compostable plastics in various streams of polymers for mechanical recycling
Juergen Priesters TOMRA	Interview	• Interaction between operational schemes at sorting platforms and presence of compostable plastics in various polymers targeted for mechanical recycling • Potential and evolution of sorting systems vis a vis contamination of compostable plastics in selected streams for mechanical recycling

A.8.0 Stakeholder Workshops

A.8.1 Workshop 1 - 23rd July 2019

A.8.1.1 Introduction

The European Commission, DG Environment, has commissioned a study on the relevance of biodegradable and compostable consumer plastic products and packaging within a circular economy. The study is in the context of the Commission's ongoing work related to plastics with biodegradable properties. The objectives of this particular study are fourfold:

3) To provide an overview of the current market and regulatory situation with regard to biodegradable/compostable plastic products and packaging, and to look at how this may change in the future;
4) To assess possible implications of the use of such products in a circular economy context, in particular on waste management and in light of conditions found in practice in home composting systems across the EU;
5) To identify conditions in which the use of such products could possibly be beneficial; and
6) To compare conditions assumed to be found in home-composting in certifications and/or legislation to conditions in practice, and to provide recommendations on possible measures to address any discrepancies.

On the 3rd June the first of two stakeholder workshops planned was carried out. The main purpose of this initial workshop was to gather information and facilitate discussion between stakeholders with varying viewpoints on biodegradable and compostable plastics. The workshop involved representatives from a range of Member States across the biodegradable plastic and packaging industries, as well as from the organic waste treatment industry, parties involved in certification– see Appendix 8 for the full attendee list.

The following report summarises the key discussions and themes from the workshop. The points reflect the various viewpoints that were raised and do not indicate a consensus position. The presentation slides from the day have been communicated separately.

This workshop was the first stage of engagement for the project. There will be ongoing one-to-one discussions and interviews. Stakeholders were also invited to send position papers or further information, or to request a meeting with the project leads.

A.8.1.2 Added value in a circular economy

Wider added value

Several areas were identified where compostable plastics could potentially add value within a circular economy. Key points are as follows:

7) Compostable plastic bags can be used in place of conventional plastic bags for organic waste collections. This can reduce the amount of residual conventional plastic in compost, and aid with the reduction of microplastics;
8) This reduces the need for pre-screening for bags at composting facilities;
9) Compostable plastics can be disposed of with other organic waste which may otherwise end up in the residual waste stream, thus improving organic waste capture rates;
10) Compostable plastics can be used to reduce the amount of food contamination in mechanical recycling; and
11) The use of compostable plastics could result in better coherence between the bioeconomy and circular economyRevenue from packaging EPR schemes could for example contribute to the treatment of organic waste.

The added value of using compostable plastic as a tool to increase the capture rates of other organic material, for example organic waste bags boosting food waste recycling rates was highlighted. When used correctly, compostable plastics have the capacity to divert organic waste away from landfill, where it would otherwise decompose releasing methane into the atmosphere (a greenhouse gas). It was however also mentioned that biowaste collected in compostable plastic bags rather than in bins could lead to greenhouse gas emissions due to fermentation in knotted bags. For this application it appears important that local composting operators are supportive of the use of such bags for organic waste collection where this is introduced as a solution for organic waste collection. It was also pointed out that "brown paper bags", to some extent an alternative, are easily compostable.

It has been outlined that compostable packaging can reduce microplastics in soil from the reduction of residual conventional plastic in compost. Although front-end processing often exists for conventional plastic, these processors are not 100% accurate and plastic parts as well as microplastics often end up in the resulting compost. It was said that compostable plastics have a displacing effect for conventional plastics within organic collections.

Contamination of other waste streams with food is a problem for the mechanical recycling industry; it was said at the workshop that using compostable plastic packaging and tableware are opportunities to decrease this contamination with food. This could potentially save mechanical recyclers both money and time, and allow composters to collect this additional organic material.

It was outlined that, at present, the way EPR schemes across Europe are set up means that revenues from such schemes does not contribute towards the treatment of organic waste. If these schemes were re-evaluated, the composting industry could potentially benefit by receiving much-needed funding to boost organic collections.

Applications which could be of added value

As outlined above, a number of stakeholders highlighted the added value of using compostables as a tool to increase capture rates of other organic materials. Many of the packaging applications that were deemed 'appropriate' are with this in mind – i.e. to increase the amount and quality of bio-waste as a feedstock for composting

Nova Institute (Nova) informed the audience that they are about to conduct a study on the appropriate applications of biodegradable plastics. This study will not be completed within the timeframe of this project; however, Nova have identified 50 applications some of which, after further assessment, may ultimately be deemed appropriate applications, and this list will be shared with Eunomia.

European Bioplastics identified the following applications for which they deem industrial compostable plastic appropriate:

12) Thin carrier bags and bio-waste bags
13) Coffee capsules
14) Tea bags
15) Fruit labels
16) Thin film applications for fruit, vegetables and perishable food products
17) Food products packaged in laminates
18) Catering items (plates, cups, cutlery)

A.8.1.3 Challenges from the use of compostable plastics

There were several key themes that came up when discussing challenges from widespread use of compostable plastics in Europe.

Biodegradation in practice

A key concern from several stakeholders was how these products biodegrade in practice. It was highlighted that, for both industrial composting and anaerobic digestion, the timeframe in test method used in EN 13432 does not reflect the actual process time at facilities. There were differing views on how this should be managed. Some parties suggested amending the EN 13432 standard to include representative time frames, whilst others suggested conditions on the facilities themselves; to include longer processing times for industrial composting (thus more mature compost which in itself has numerous benefits), or compulsory composting of the digestate output from AD facilities. Despite differing opinions on how this should be achieved, there was a consensus that test methods should align as much as possible with actual facility conditions.

There was a statement that in relation to compostable plastics '100% biodegradation' is not scientifically possible. However, if a product does not 'fully' biodegrade, it does not necessarily mean that there is microplastic left. Eunomia were pointed to a study regarding full biodegradation, and this will subsequently be explored and analysed.

Suez showed key results from testing of packaging samples from the market with claims of compostability and biodegradability. Suez tested the processing of such samples in their laboratory, in conditions representative of their actual facility conditions – including anaerobic and aerobic composting, and mechanical plastic recycling facilities.

They found that compostable plastic bags do not degrade entirely in anaerobic conditions, and that there is a risk of still finding microplastics in composts and digestates after the end of the waste treatment operation. Suez also concluded that the standards for compostable plastics do not reflect industrial conditions, including the duration, temperature and level of aeration.

They also found that generally compostable plastics get stuck in rotors and screws in the processing equipment, slowing down the process and affecting machinery. As such, the waste managers found that it was more effective to screen out the products at the beginning of the process and dispose of as residual waste.

Potential drawbacks in the circular economy context

Potential drawbacks were highlighted for biodegradable and/or compostable plastics. One key issue is that when these plastics are composted, the energy and raw materials used for production are mostly lost. They mostly degrade into water and carbon dioxide and as such do not add nutritional benefit to the compost. This is a contradiction with the circular economy, in which resources should be kept for as long as possible and the maximum value should be extracted whilst in use.

Concerns were also highlighted that the products in which compostable plastics are deemed 'appropriate' could instead be prevented entirely, following the waste hierarchy – for example through the use of reusable alternatives to single use options. Another example given was fireworks; it was suggested that instead of replacing the conventional plastic in fireworks with biodegradable plastic, the use of fireworks should be prevented, and perhaps even banned entirely. A counterargument was that food packaging, for example, cannot be prevented entirely and that some packaging actually helps reduce food waste.

Interference with mechanical recycling

Concerns were raised by some parties about the interference that compostable plastics can have on mechanical recycling. It was outlined that flexible compostables can interfere with equipment, however it was not established whether this was any more than other flexible non-targeted plastics. There were fears that there could be a quality decrease of the recyclate output if rigid plastics such as PLA were to go through the recycling process without being removed. Eunomia mentioned a study that found that a small amount of PLA contamination in dry recycling of PET does not cause issues. Another recent study was however mentioned which found that 0,1% PLA is enough to declassify PET recyclates. Eunomia will seek to explore this further and compare expected quantities to 'allowed' contamination rates in the context of the current recycling market landscape.

Lack of homogeneity

One challenge that was presented was the lack of homogeneity in products, an example given was an industrially compostable PLA bottle with a conventional plastic PE lid and a conventional PET wrapper that had been found on the market. This, inevitably, leads to problems in the waste management of these products, as consumers are extremely unlikely to separate the three.

Limited acceptance in composting facilities

As outlined in section 0, Suez found that compostable plastics are often sorted out at the entrance of composting plants as they regularly get stuck in equipment. It was highlighted that a facility can decide themselves whether they accept compostable plastics, and this varies widely from facility to facility. There is generally low acceptance for rigid compostable plastic packaging items, and acceptance is higher for flexible packaging including organic waste bags.

The European Composting Network presented a map – to be finalised – showing the acceptance of compostable plastics across Europe. This map shows 'advanced', 'partial' or 'low' acceptance levels for compostable plastic for Member States. Eunomia will seek to get this map once it is finalised, to influence its guidance for the appropriateness of the use of compostables across Europe.

The DUH presented their 2015/16 survey, in which they found that 80% of the composting plants in Germany that responded called *all* products made from biodegradable plastics as "unwanted impurities". A further 77% of these plants screen compostable plastic bags (including organic waste bags) out before the composting process.

A.8.1.4 Consumer information, standards and certification schemes

Definitions

Concerns and opportunities regarding consumer information, standards and certification schemes were discussed. It was primarily identified that clear definitions are key, and that there is no clear definition of home-composting. The standard for home-composting that is being developed within CEN refers to a 'well-managed system', whereby it is not clear what this means and whether it is appropriate to develop a standard which would assume conditions which may be unlikely to be found in most cases in practice

Standards and certifications

It was highlighted that the communications regarding test methods, standards and certifications, and related claims, are extremely difficult for consumers to understand. It is also difficult for those working in the industry to understand the methods, standards and certification, which often results in further misinformation. European Bioplastics agreed to write a short one-page document on the technical content of the standards to be made available to the Commission and Eunomia.

It was identified that there are products on the market, such as PE bags, fraudulently using certifications as 'compostable'. It was made clear that this is not misinformation but fraud, and that instances should be reported to certification bodies. The process by which certification bodies verify products on the market was discussed. It was explained that there is a team monitoring the market to ensure all certified products on the market are compliant.

In regards to home-composting, there is a standard currently being written by industry stakeholders for CEN. It was outlined that an ecotoxicity test method within a home-composting standard is not possible, as nitrates and worms vary widely across systems, amongst other factors. Eunomia will seek to look at the standard that is being developed to guide this project.

Consumer perceptions and labelling

There were concerns raised about the consumer perception of a product as being home compostable if it is industrially compostable and vice versa. Oliver Ehlert from DIN CERTCO stated that purely from a standards point of view, a product was not necessarily industrially compostable if it was certified home compostable due to the time frames involved. It was highlighted that this could be extremely confusing for consumers and should be addressed.

The labelling of products was discussed in detail, and it was agreed by all parties that labelling needs to be extremely clear to limit misunderstanding from consumers. There needs to be clear directions on which waste stream the product should go in. There should be no misleading information such as 'plastic-free', or broadly unjustifiable claims such as 'good for the environment'.

A.8.1.5 Summary of Workshop Themes

Challenges from the use of compostable plastics in Europe were discussed, however various views were presented on how the waste from these products are managed in practice. Several accounts were given of the impacts of plastic in industrial composting, anaerobic digestion, and mechanical dry recycling streams, and waste managers believed that their facilities are not able to process these wastes. Home composting facilities were also discussed, and it was highlighted that a definition of home composting is required so that stakeholders can discuss the role of compostables within home composting environments and their place in the circular economy.

There was a consensus in the room that no parties felt compostable/biodegradable plastics were appropriate in applications where there were existing, functional materials which had an appropriate disposal method which is considered better or equivalent in the waste hierarchy. However, stakeholders identified some applications where compostables appear to be of added value. It was suggested that perhaps compostable plastics could replace products which have the tendency to leak into the natural environment, or to prevent organic materials from contaminating other streams.

Benefits of using compostables in certain circumstances were highlighted. A main point from a number of attendees was the added value of compostable plastic bags as a tool to increase the capture rates of other organic material, for example organic waste bags boosting food waste recycling rates. It was highlighted by some stakeholders that – when used correctly – compostable plastics have the capacity to divert biowaste from landfill, reduce impurities in organic waste and reduce microplastics.

Some stakeholders suggested that legislation could aid the use of compostable packaging in 'appropriate' applications. It was also highlighted that education across all Member States is necessary if such products are to be used more widely, both at the consumer and waste management level.

Concerns regarding misinformation and fraud were addressed, and this was highlighted as a key issue for various points in the chain. In particular, it was agreed that the labelling of these products can largely be misleading to consumers and that further guidance and legislation is required to ensure this does not continue.

A.8.1.6 Agenda and attendees

Agenda

Agenda Item	Time
19) **Registration and refreshments**	**9:30**
20) **Introduction to project from Commission**: the background context for the study; the Commission's expectations and objectives **Q&A**	**10:00**
21) **Overview of Initial Research Findings** a. Data and Trends on current and future market for biodegradable/ compostable plastic products and packaging - Simon Hann, (Eunomia) b. Compost and Recycling - Enzo Favoino, (SADPM) **Q&A**	**10:15**
Lunch	**12:00**

Agenda Item	Time
22) **Challenges from the more widespread use of compostable plastics in Europe** a. Compostable plastics and their impacts in composting in Europe - Marco Ricci-Jürgensen (European Compost Network) b. Biodegradable plastics in composting – results of survey Philipp Sommer (DUH) c. **Waste Management Perspective - Nicole Couder (Suez)** **Discussion** i. Options for mitigating adverse impacts from compostable plastics including adequate **disposal.**	**13:00**
Break	**14:15**
23) Conditions/ applications for which the use of compostable products and packaging is of added value in a circular economy a. **Kristy-Barbara Lange (European Bioplastics)** b. Mariagiovanna Vetere (Natureworks) **Discussion:** i. What could be criteria for identifying products where compostable plastics are **of *added value* (e.g. compared to making a product/ packaging reusable, recyclable or out of an alternative material).**	**14:30**
24) The role of consumer information, standards and certification schemes in achieving best possible use of compostable plastics a. Oliver Ehlert (DIN CERTCO) b. Philippe Dewolfs (TÜV Austria) c. Development of a European Standard for Home composting Tony Breton (Novamont) **Discussion:** i. Are today's tests and standards fit for purpose in light of conditions to be found in home-composts, industrial composting and AD plants? ii. Could better instructions/information/labelling be provided to households and waste operators to ensure compostable plastic products are managed under optimal conditions?	**15:30**
25) Closing Remarks and Next Steps	**16:30**

Attendees

Name	Organisation
Kristy-Barbara Lange	European Bioplastics
Hasso von Pogrell	European Bioplastics
Tony Breton	Novamont
Mariagiovanna Vetere	Natureworks
Steve Dejonghe	Looplife Polymers
Juli Vol	TIPA
Chaim Gabriel Waibel	Plastics Recyclers Europe
Philippe Dewolfs	TUV Austria
Oliver Ehlert	DIN CERTCO
Katharina Schlegel	BASF
Thomas Grusemann	TUV Rheinland
Ioana Popescu	ECOS
Marco Ricci-Jürgensen	European Compost Network
Erwin Lepoudre	Kaneka
Philipp Sommer	Environmental Action Germany (DUH)
Nicole Couder	Suez
Denis Pohl	Federal Environment Ministry Belgium
Sophie Jenerwein	DEKRA
Michael Carus	Nova Institute
Simon Hann	Eunomia Research & Consulting
Rosy Scholes	Eunomia Research & Consulting
Enzo Favoino	SADPM
Leonardo Mazza	EU Commission DG ENV
Bettina Lorz	EU Commission DG ENV
Maja Desgrees du Lou	EU Commission DG ENV
Werner Bosmans	EU Commission DG ENV
Emilien Gasc	EU Commission Secretariat General
Fleur van Ooststroom Brummel	EU Commission DG GROW
Andrea Accorigi	EU Commission DG RTD
Hans-Christian Eberl	EU Commission DG RTD
Peter Eder	EU Commission JRC

A.8.2 Workshop 2 – 22nd October 2019

A.8.2.1 Introduction

The European Commission, DG Environment, has commissioned a study on the relevance of biodegradable and compostable consumer plastic products and packaging within a circular economy. The study is in the context of the Commission's ongoing work related to plastics with biodegradable properties.

The objectives of this particular study are to:

1) provide an overview of the market and regulatory situation with regard to biodegradable/ compostable plastic products and packaging;
2) assess possible implications of the use of such products in a circular economy context, in particular on waste management and in light of conditions found in practice in home composting systems across the EU (in terms of leakage of compostable plastics into the open environment and for the quality of the compost); and,
3) identify conditions/ applications in which biodegradability/ (home) compostability of products or packaging could be of added value when compared to reuse and other forms of recovery and clarify the basis for establishing such conditions/ applications. Identification of relevant benchmarks in relation to the "added value".
4) provide an overview of biodegradability criteria set in existing home-compostability frameworks (standards, legislation, certification schemes)
5) assess the practical relevance and limitations of such criteria in light of conditions found in practice in home-composting systems across the EU and identify possible measures for addressing discrepancies.
6) develop related recommendations.

In support of the overall objectives, a stakeholder workshop was carried out on the 23rd October. This was the second of two workshops, and was centred on the following:

- Presenting research on the market and possible implications of the use of biodegradable / compostable plastic products and packaging within a circular economy;
- Getting feedback on a preliminary proposal for criteria under which the use of such products could be beneficial; and
- Discussion of the findings related to the effectiveness of home composting as a waste management route for plastics.

The workshop involved representatives from a range of Member States, industry bodies, manufacturers, waste processers and parties involved in testing and certification.

The following report summarises the key discussions and themes from the workshop. The points reflect the various viewpoints that were raised and, unless stated, do not indicate a consensus position. The presentation slides from the day have been communicated separately.

A.8.2.2 Research Findings

Eunomia presented key findings from the market research and implications of using such products. Key topics that were addressed were:

- The size of the market and most common applications;
- Issues with labelling / communication of products;
- Main concerns about the products from composters;
- Main concerns about the products from plastic recyclers;
- How compostable packaging fits with recycling targets from the Packaging and Packaging Waste Directive (PPWD); and
- Risks of littering such products.

Some of these topics did not promote much new discussion, but can be seen in more detail in the accompanying presentation. Discussion was had particularly around processing concerns and how these products contribute towards recycling targets. This discussion is summarised below.

Processing Concerns

It was highlighted that there is a need for detailed waste composition analyses at composting facilities, to identify the plastic materials and products that are present in compost, both compostable and non-compostable. It would be particularly interesting to look at composition in Italy compared to a country with lower use of compostable products.

There was also discussion on how much of contamination in conventional plastic recycling is made up of compostable and non-compostable contamination. It was presented that studies in Italy show an average compostable plastic contamination rate of 0.84% prior to sorting, but it is unclear how much non-compostable contamination there is on top of this.

It was suggested that composters concerns are partly operational and partly perception, and that the clear labelling of 'suitable' products could mitigate many issues.

As in the first workshop, it was highlighted that the Extended Producer Responsibility fee for compostable products goes towards processing conventional plastics, and this should be amended to support the composting of such products.

Contribution to Recycling Targets

Article 6a (4) of the PPWD 94/62/EC states that;

> *"For the purposes of calculating whether the targets laid down in points (f) to (i) of Article 6(1) have been attained, the amount of biodegradable packaging waste that enters aerobic or anaerobic treatment may be counted as recycled where that treatment generates compost, digestate, or other output with a similar quantity of recycled content in relation to input, which is to be used as a recycled product, material or substance. Where the output is used on land, Member States may count it as recycled only if this use results in benefits to agriculture or ecological improvement."*

It is unclear whether the compostable plastics meet these criteria, particularly as the terms ‘similar’ and ‘ecological improvement’ are undefined.

In the workshop, European Bioplastics highlighted that there is no efficiency recycling threshold for composting, and that the targets for conventional recycling do not work for compostable plastics. It was suggested that these amended to make it possible for compostable plastic packaging to contribute to such targets.

It was decided that whether a product meets the recycling targets should be considered at application specific level, as it is easier to quantify for some products over others.

A.8.2.3 Suitability of Standards

Concerns were highlighted over whether the time frame used in the EN 13432 standard is representative of the actual time frame used in composting facilities. Composting facilities typically make the composting stage as short as possible to save resource. This is sometimes known as ‘biological drying’ and produces compost that is deemed to be unstable and lacks nutritional value. It was said that a clear distinction needs to be made between biological drying and proper composting, which products a stable output.

It was also outlined, however, that many other naturally occurring materials would not typically degrade in a short composting process and often have to be re-processed. For example, woody materials are often re-processed, sometimes several times.

It was made clear that the standard is not designed to reflect real life, and aims to show inherent industrial compostability – a quality of the material itself.

The ecotoxicity tests with EN 13432 do not include tests for soil organisms such as earthworms, however only test plant germination and growth. An earthworm toxicity test is included in the draft home composting standard, and some people think this should be added to the EN 13432 industrial composting standard. Several parties also thought that a nitrification inhibition test should be included, as in the home composting draft.

Different views were presented on whether EN 13432 should be updated. Key points were:

- There is no point updating the standard until there is standardisation of the composting process or legislation limiting digestate being applied directly to land;
- The standard should be updated to include nitrification inhibition and an earthworm toxicity test;
- The standard should be changed to reflect actual conditions, particularly the length of the process; and
- The standard should be updated now, in line with Essential Requirements.

It was highlighted that the standard is due to be reviewed in 2020, and that a mandate from the Commission would be necessary to update it.

A.8.2.4 Criteria Development

A key part of this project is to use the research conclusions highlighted in the previous sections to help derive a set of criteria that can help to identify beneficial uses of compostable plastics in the context of a circular economy.

Criteria Ranking

An exercise was undertaken to include the stakeholders in this criterion setting process. The criteria presented to the stakeholders had primarily been derived from position papers provided for the project, with others being developed by Eunomia.

The stakeholders were asked to separate the criteria using a tier system, with the expectation that a consensus could be built around a core set of criteria. The tier system is as follows:

- **Tier 1 –** Highly important criteria as identified through the project research; the implication is that **all** should be met.
- **Tier 2 –** May highlight an important requirement, but the evidence base or the ability to measure this does not allow effective criteria to be developed at this stage.
- **Tier 3 –** Likely to be low priority aspects with mixed evidence and difficulty measuring.

The stakeholders were also invited to add any additional criteria, or reject any of the criteria proposed.

The stakeholders were split into five mixed groups so that a range of opinions were present in each. The results from each group are shown in Table 10. Green cells indicate a Tier 1 criterion, yellow cells a Tier 2, red cells a Tier 3, and blank cells are rejected criterion.

Table 10: Results from the group exercise deciding importance and feasibility of criterion

	#	1	2	3	4	5
Effective organic waste collection, sorting and treatment infrastructure should be in place that accepts compostable plastic	1					
The product is likely to end up in organic waste collection	2					
The material/product is likely to be contaminated with food	3					
The product being compostable reduces non-biodegradable plastics in organic waste collections	4					
‘Semi-rigid’ compostable plastics should only be used in ‘closed’ systems	5					
Compostable material should not be used in products that contain or come into contact with human or animal waste	6					
There is a low likelihood of item being effectively recycled (recycling prioritised over composting)	7					
The packaging is ‘rapidly consumed’	8					
The co-existence of compostable and non-compostable plastics within the same product group should be avoided	9					
There are no alternative reusable solutions available	10					
There is an absence of suitable/available ‘natural’ compostable materials	11					
The products should meet EN Standards	12					
Compostable plastic should not be mixed with other non-compostable materials	13					
The product should bring ‘environmental benefits’	14					
Compostable plastics are at least partly made from renewable materials	15					
The correct waste management route is clearly identifiable for the consumer/user	16					
The term ’biodegradable’ should not be used	17					

There was clearly a majority agreement that the following should be core criteria:

1) Effective organic waste collection, sorting and treatment infrastructure that accepts compostable plastic should be in place.
2) The products should meet EN Standards for composting of packaging or plastic products.
3) Compostable plastic should not be mixed with other non-compostable materials.
4) The correct waste management route should be clearly identifiable for the consumer/user.
5) The term 'biodegradable' should not be used.

Many groups agreed that the criteria 'product is likely to end up in organic waste collection' was an important criterion, however there is a low possibility of being able to measure this.

The criteria 'The co-existence of compostable and non-compostable plastics within the same product group should be avoided' was highly divisive, with some groups grouping this as a Tier 1 criterion, and others rejecting it entirely.

The criteria on the product bringing environmental benefits was also highly divisive, possibly as it is important but very difficult to measure.

Several stakeholders highlighted that further clarity is needed on some of the criteria, particularly in regards to the wording. It was also highlighted that many of the criteria are moving targets, for example the criteria 'there is a low likelihood of item being effectively recycled' may be true now for a plastic film but could improve with the introduction of chemical recycling.

Decision Tree

Using these criteria, it is possible to develop a decision-making process that identifies where compostable plastics could provide added value.

The stakeholders were asked to follow this decision tree for common applications to address the following questions:

- Can the decision tree be used to determine a positive list of applications for which the use of compostable plastics should be allowed (or promoted) based on their added value (while closing the door to other applications)?
- Is this decision tree approach a useful and effective way to assess (and communicate) the pros and cons of designing a given application for composting?
- Should trees be different depending on whether one is considering designing a product/packaging for industrial or home-composting?
- Is there a benefit of creating categories based on application for the certification bodies?
- Would certification bodies use such a tool to help them determine suitable applications to provide certification for?

There was a consensus opinion that the decision tree was fairly simple to follow for the applications visited and overall useful, however it was mentioned that the tree may not be appropriate for more complex applications such as multilayer packaging and adhesives.

It was deemed that it would be a useful tool for certification bodies, as they are currently having to decide on a product specific basis whether compostable plastic is used suitably and certification has been earnt.

It was not thought that a decision tree was necessary for home composting, rather the very few suitable applications could be listed. The consensus position was that the decision tree was suitable for industrial compostability only.

One group asked for a decision box on whether the product is collected with organic waste or not, however this would result in the decision tree no longer being material neutral but assumes a compostable plastic is used.

It was also highlighted that 'unacceptable food waste' needs further definition, and was suggested that a level of contamination may be useful.

The criteria that the compostability should be effectively communicated to consumers was not in the tree. This was due to the fact that Eunomia think this could simply come after the decision-making process, however not all stakeholders agreed with this. The communication regarding these products will be fundamental to their effectiveness and there were suggestions that this should be incorporated into the decision tree.

It was also stated that it needs to be clear that the waste hierarchy is being followed, for example food waste reduction needs to be prioritised over food waste capture.

It was decided that it should be asked explicitly in the decision tree whether the product is banned by law, for example single use cutlery.

A.8.2.5 Home Composting

Due to time restrictions, the interactive session on the home composting of plastics did not go ahead as planned. Stakeholders were invited to review the information supplied in the workshop briefing paper, and send over position statements.

A brief discussion was had on the merits of home composting plastics. Overall, home composting is not being pushed as a suitable waste management solution. Most stakeholders agreed with this sentiment, as a circular economy cannot be promoted if people are disposing of things in their own garden. It was highlighted that in industrial composting, nutrients are effectively recycled into crops – so long as the compost is mature.

As such, it was deemed to not be imperative to discuss with stakeholders what is happening in practice in home composting systems compared to certifications, but instead why home composting is not deemed a suitable waste disposal method.

A.8.2.6 Agenda, Attendees and Apologies

Agenda

Agenda Item	Time
1) **Registration and refreshments**	9:30
2) Introduction to project from Commission: the background context for the study; the Commission's expectations and objectives	10:00
3) Presentation – Overview of study and current findings • **Market – further information building from first workshop** • **Labelling and Communication** • **Issues in composting and recycling** • **Compostable Packaging Contributing to Recycling Targets** • **Risks of Littering**	10:15
4) **Q&A on current findings**	10:55
5) Introduction to criteria setting for beneficial use of compostable plastics	11:15
Lunch (BU-5 canteen)	12:00
6) Interactive session on criteria setting and the decision process	13:00
7) Summary and feedback of interactive session	14:30
Break	14:45
8) Presentation of findings from investigation into home composting as treatment method for compostable plastics	15:00
9) Interactive session: Q&A, feedback and discussion on the merits of home composting of plastics	15:45
10) Closing remarks and next steps	16:30

Attendees

Name	Organisation
Kristy-Barbara Lange	European Bioplastics
Philippe Dewolfs	TUV Austria
Ioana Popescu	ECOS - European Environmental Citizens Organisation for Standardisation
Steve Dejonghe	Looplife Polymers
Oliver Ehlert	DIN CERTCO (TUV Rheinland)
Nicole Couder	Suez
Denis Pohl	Federal Environment Ministry Belgium
Sophie Jenerwein	DEKRA
Chaim Waibel	Plastics Recyclers Europe (PRE)
Katharina Schlegel	BASF
Darko Horvat	Republic of Croatia Ministry of Environment and Energy
Paolo La Scole	Novamont
Petr Bažil	Ministry of the Environment, Czech Republic
Bruno De Wilde	OWS Lab and consulting services
Stephan Dreyer	Federal Environment Ministry Germany
David Nordqvist	Nestle
Lara Dammer	Nova Institute
Merja Saarnilehto	Ministry of the Environment, Finland
Anindya Mukerjee	GO!PHA
Pablo Rodriguez Porras	Ministry for the Ecological Transition - Spain
Simon Hann	Eunomia Research & Consulting
Rosy Scholes	Eunomia Research & Consulting
Leonardo Mazza	EU Commission DG ENV
Bettina Lorz	EU Commission DG ENV
Maja Desgrees du Lou	EU Commission DG ENV
Werner Bosmans	EU Commission DG ENV
Silvia Forni	EU Commission DG ENV

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