Novel packaging films and textiles with tailored end of life and performance based on bio-based copolymers and coatings.

D.4.7 LCA and organic recycling of packaging by home composting and anaerobic digestion

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Acronyms

AVG	Average
BBI-JU	Bio-Based Industries Joint Undertaking
EC	European Commission
EU	European Union
PLA	Polylactic acid
REL	Relative
SD	Standard deviation

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Introduction

In this deliverable the environmental, cost and social impacts of the demonstrators developed in BIONTOP will be summarized and compared with reference products. The environmental impacts are assessed by using the ReCiPe 2016 Endpoint method which compiles the impacts on specific problems such as Climate Change or Eutrophication or Fossils resources use into three Damage impact categories: Damage to Ecosystems, Damage to Resources and Damage to Human health. Note that the ReCiPe method was slightly adapted so it could account for carbon dioxide uptake during biopolymer production and biogenic CO2 emissions at the end-of-life. A cradle-to-grave approach is followed, which means that the impacts of the production stage and the waste treatment at the end-of-life are included. The use stage is excluded because all packaging is assumed to perform equally. If the systems under study provided different outputs, the European average market supply of these goods was included of an additional “Expanded system” life cycle stage of the other system that was not providing these outputs. For example: incineration with energy recovery of a packaging film yields electricity and thermal energy that can be captured and used while these goods are not produced when the packaging would be composted. Therefore, all of the studied systems were corrected for their outputs resulting in comparable systems. Note that this means that the impact assessment results in this report are only valid for this particular study and cannot really be used in comparisons with LCA results of other studies that are using different system boundaries.

Furthermore, the suitability of the developed packaging to be treated via home composting and anaerobic digestion, another way of organic recycling such as industrial composing, was evaluated. In order to be home compostable a product must fulfil the requirements of the European norm EN 13432 Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging (2000) with demonstration of biodegradation and disintegration at ambient temperature:

- Heavy metals and fluorine requirements as prescribed by EN 13432 (2000);
- Minimum volatile solids content of 50% on dry matter;
- Complete (> 90%) biodegradation at ambient temperature within 1 year;
- Complete (> 90%) disintegration at ambient temperature withing 6 months,
- No adverse effect on compost quality (including plant toxicity).

This testing program is applied in certification schemes such as OK compost HOME of TÜV AUSTRIA Belgium and the DIN Geprüft HOME COMPOSTABLE logo of DIN CERTCO. In this project focus was given to biodegradation and disintegration as these are the most difficult parameters to fulfil. All developed products are PLA (polylactic acid) based, making it a challenge to obtain home compostable products, as PLA normally needs a thermal trigger before hydrolysis and biodegradation starts.

For anaerobic digestion no standard specification with requirements is existing, nor a testing scheme has been developed by a certification institute. Still, OWS has developed a draft proposal for such a scheme and testing was performed according to this scheme. The biodegradation and disintegration under dry thermophilic (52°C) and mesophilic (37°C) anaerobic conditions was considered as these packaging products are eventually more likely to be included in the organic fraction of municipal waste and treated in “dry” systems opposed to wet anaerobic conditions. Also, mesophilic conditions were considered as one of the objectives of the project was to develop PLA products that are also degradable under mild conditions.

1. LCA results

1.1. Home composting in LCA

It is difficult to assess the environmental impacts of home composting because there are many ways to perform composting at home and more importantly, composting at home is not monitored and not optimized as is the case in industrial composting settings. When composting is done at suboptimal conditions, composting may produce less compost and carbon dioxide and release more methane, ammonia and dinitrogen oxide. Methane and dinitrogen oxide are much more powerful greenhouse gasses than carbon dioxide and ammonia is a harmful gas on many environmental problems and is an important impact contributor on the problem of acidification. However, home composting has also benefits, because the organic waste does not need to be transported to waste treatment plants, no transport, waste treatment facilities nor machinery is required, apart from a bin, which is usually made of plastic. Therefore, the impacts of home composting were estimated by data for industrial composting from a widely used LCA-database, with removing the data for waste transportation, machinery and other capital goods and adding the requirement of the plastic bin. Because of this, the home composting results are likely to represent a best case. As such, assessing the environmental impacts of home composting is always subjected to a relative high degree of uncertainty and all results must be interpreted with care. Furthermore, given that BIOnTOP is a research project, a large number of assumptions were used and any assessment results should be viewed as indications or potential impacts rather than facts.

1.2. Tea bags

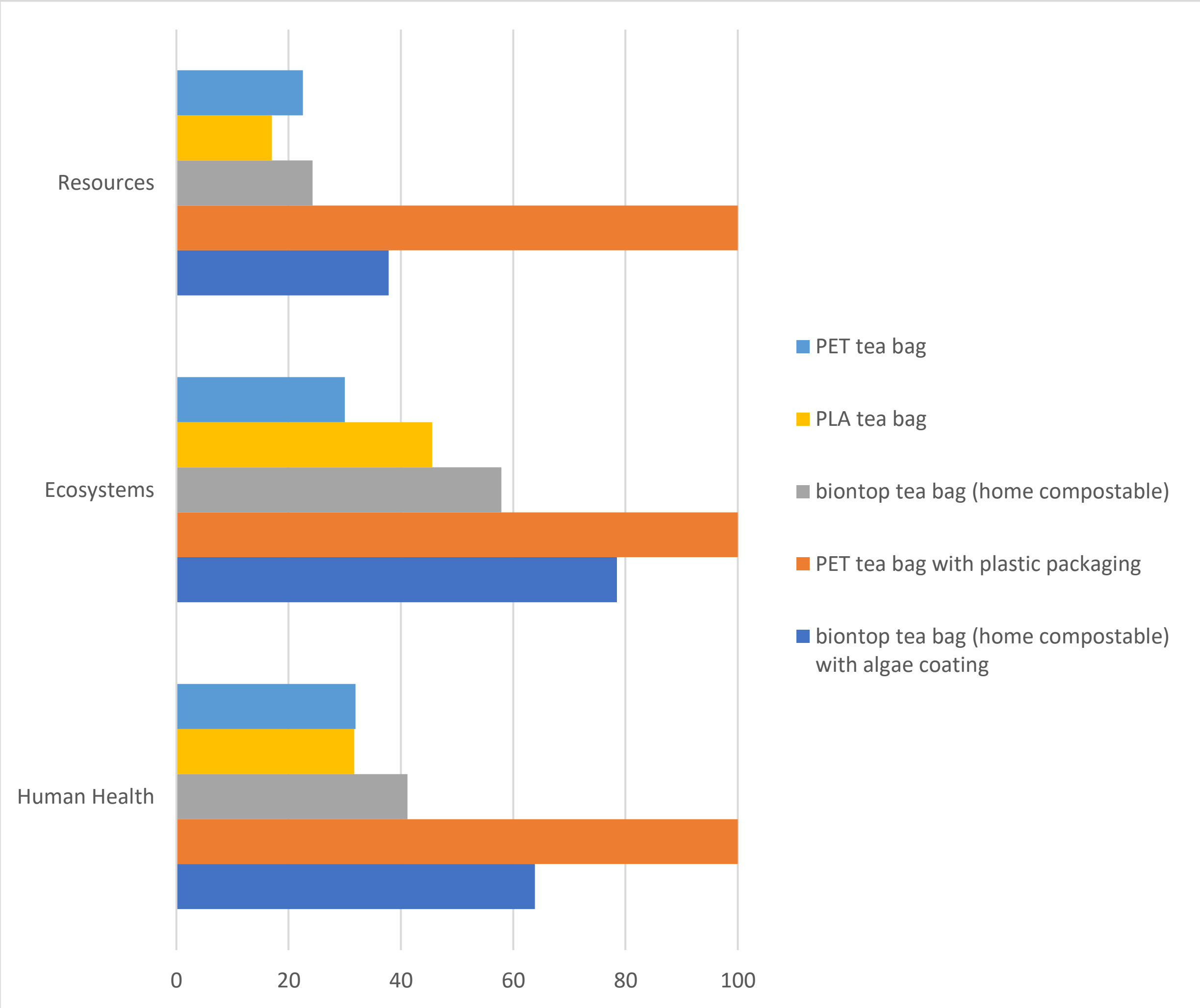


Figure 1: Environmental impacts of different tea bag formulations calculated by the ReCiPe 2016 (H) Endpoint method, corrected for biogenic and fossil CO2 emissions.

The LCA is conducted from cradle-to-grave and takes into account the impacts at the production stage and end-of-life stage. The use stage is excluded because it is similar for all variants of the tea bag. Note that in the end-of-life stage, also the tea itself is included in the assessment because usually the tea is not removed from the tea bag at the end-of-life treatment. The blue, yellow and grey bars in Figure 1 represent two reference tea bags, one made of PET, a fossil based plasic, and one made of PLA, a biobased plastic, and the biontop tea bag, which is based on PLA but also includes other biopolymers and a copolymer specifically developed in biontop. Our assessment indicates that the biontop tea bag (grey bar) has higher impacts on Ecosystems and Human health than the reference tea bags but a comparable, although higher, impact on Resources. The orange and dark blue bars represent a PET-based tea bag confined in plastic LDPE packaging and the biontop tea bag, which was coated with alginate as to provide a similar aroma barrier as the plastic packaging. The plastic packaging of the PET-based tea bag is assumed to be incinerated, while the alginate coating of the biontop tea bag is assumed to be removed upon immersion of the tea bag in hot water and enter the household wastewater treatment system (although it also might be consumed along with the tea). In contrast to the first three variants of the tea bag, the coated tea bag has lower impacts on Ecosystems, Resources and Human health than the PET-tea bag of which the plastic packaging is incinerated. Clearly, the difference lies in the incineration of the secondary plastic packaging. While the specific impact contributions of the different life cycle stages and components are confidential, it can be mentioned that for the biontop tea bags, by far most of the life cycle impacts are caused by the production phase of which more than half of the impacts are caused by the used materials. Overall, the raw materials contribute roughly about 50% of the total life cycle impacts, on average across the three impact categories.

1.3. Flexible films and trays

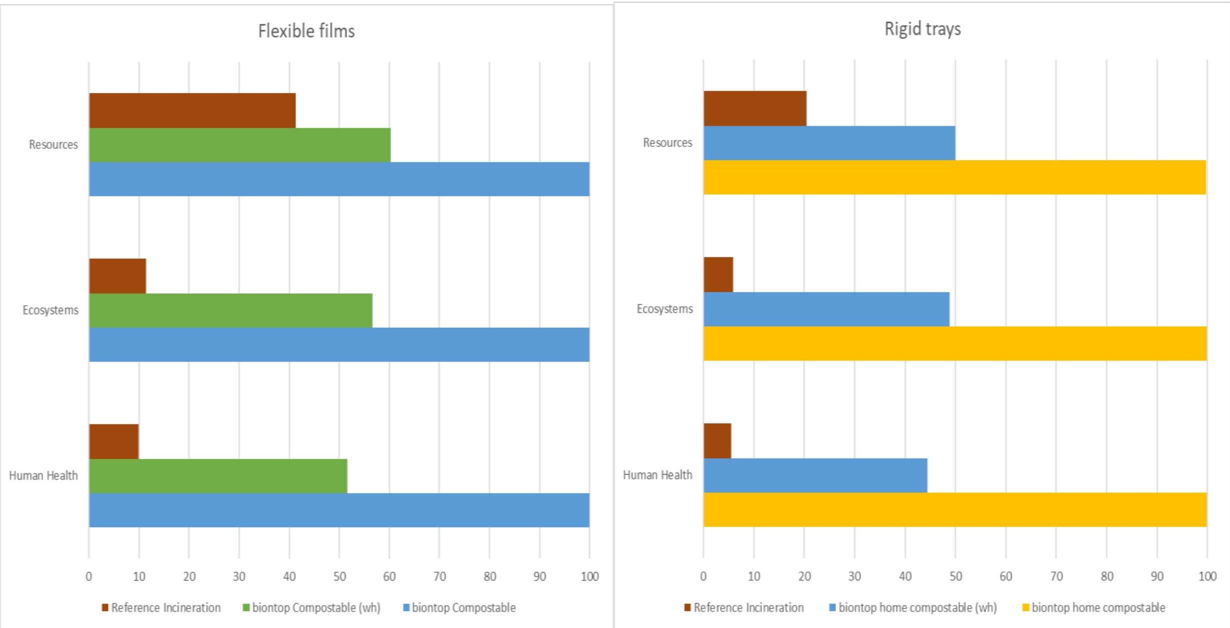


Figure 2: Environmental impacts of different films and trays calculated by the ReCiPe 2016 (H) Endpoint method, corrected for biogenic and fossil CO2 emissions.

The biontop compostable films and trays were calculated as two variants, a 'standard' one and the 'wh' one with decreased electricity use through the use of industrial waste heat as energy source for drying processes of the raw material granulates. The reference film is made from fossil-based LDPE, the reference trays is assumed produced from fossil based PP, and both are assumed to be incinerated at the end-of-life. The compostable biontop films and trays are found to have higher impacts on each of the three environmental impact categories, although using waste heat as energy source for drying processes of the raw materials just prior of film or tray production reduces the impacts with at least 40% for the films and for trays with 50%. While the specific impact contributions of the different life cycle stages and components are confidential, it can be mentioned that the most impact contributing life cycle stage is the production stage with the newly developed copolymer as the major impact contributor of the production process. While the copolymer enables increased processability of biopolymers such as PLA, its production is not yet optimized and not produced on an industrial scale and therefore relatively large amounts of electricity are needed to produce the copolymer. The impact calculations were done by using the European production mix for electricity from the EcoInvent 3.8 database, which includes fossil and sustainable sources of electricity production. Aside from electricity consumption and copolymer production, also the biopolymers (other than PLA) used in the film and tray production have relevant (>15%) impact contributions to the production stage and to the Life cycle impacts on Ecosystems, Resources and Human health.

If it is found to be impossible to decrease the impacts of the copolymer or the used biopolymers, it might be better to aim for mechanical recycling rather than composting, especially when it would be possible to obtain closed loop systems, where the recycled material can used again to produce the same commodities. However, it is hard to achieve a closed loop recycling system for food packaging plastics, even for materials such as PET for which recycling lines already exist for decades.

1.4. Oriented nets

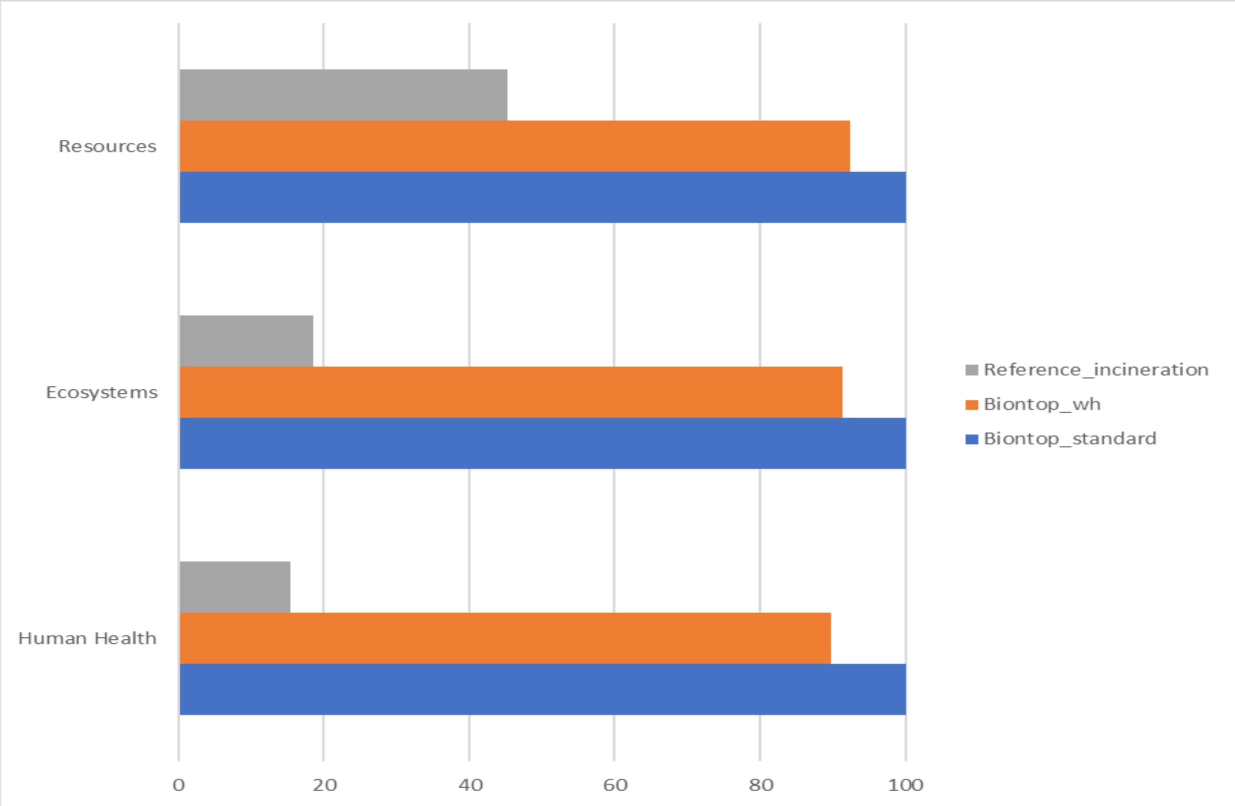


Figure 3: Environmental impacts of different food nets calculated by the ReCiPe 2016 (H) Endpoint method, corrected for biogenic and fossil CO2 emissions.

The biontop compostable food nets were calculated as two variants, a 'standard' one and the 'wh' one with decreased electricity use through the use of industrial waste heat as energy source for drying processes of the raw material granulates. The reference net is made from LDPE plastic and is incinerated after use. A cradle to grave approach is followed, excluding the use phase. Our results indicate higher environmental impacts on Ecosystems, Resources and Human health for the biontop nets, although already a 10% decrease in impact seems obtainable by switching from grid electricity to industrial waste heat for material drying processes. While the specific impact contributions of the different life cycle stages and components are confidential, it can be mentioned that the most impact contributing life cycle stage is the production stage with the newly developed copolymer as the major impact contributor of the production process. While the copolymer enables increased processability of biopolymers such as PLA, its production is not yet optimized and not produced on an industrial scale and therefore relatively large amounts of electricity are needed to produce the copolymer. The impact calculations were done by using the European production mix for electricity from the EcoInvent 3.8 database, which includes fossil and sustainable sources of electricity production. The impacts of the food nets could therefore be reduced by decreasing the electricity consumption and through using more sustainable sources of electricity. Note that the biopolymers (other than PLA), used in combination with the copolymer, also represent relevant impact contributions (>10%) to the impacts on Ecosystems, Resources and Human health of the production stage. However, the field of biopolymer production is continuously improving and in the process of optimizing. Therefore, it is estimated that future impacts of biopolymer production will decrease. Because of these considerations, it should be noted that the current impact assessment is only valid, taking the uncertainty of a research project into account, for the used materials at the timeframe of the Biontop project.

2. Home composting

2.1. Tea bags (yarn)

A whole range of yarns with different compositions were evaluated for degradation under home composting conditions as it was observed that the production of the yarns form the compound decreased the biodegradation rate under these conditions. Finally, a PLA-based yarn was developed that fulfilled the 90% relative biodegradation requirement within 1 year (Figure 4). The evolution of the disintegration under home composting is shown in Figure 5. The maximum allowed test duration for disintegration under home composting conditions is 26 weeks. A complete tea bag with alginate coating, to keep the flavours inside, was produced and checked for disintegration under home composting conditions. After 12 weeks of composting the tea bag was completely falling apart (Figure 6). Based on these results it can be concluded that a home compostable PLA tea bag was developed.

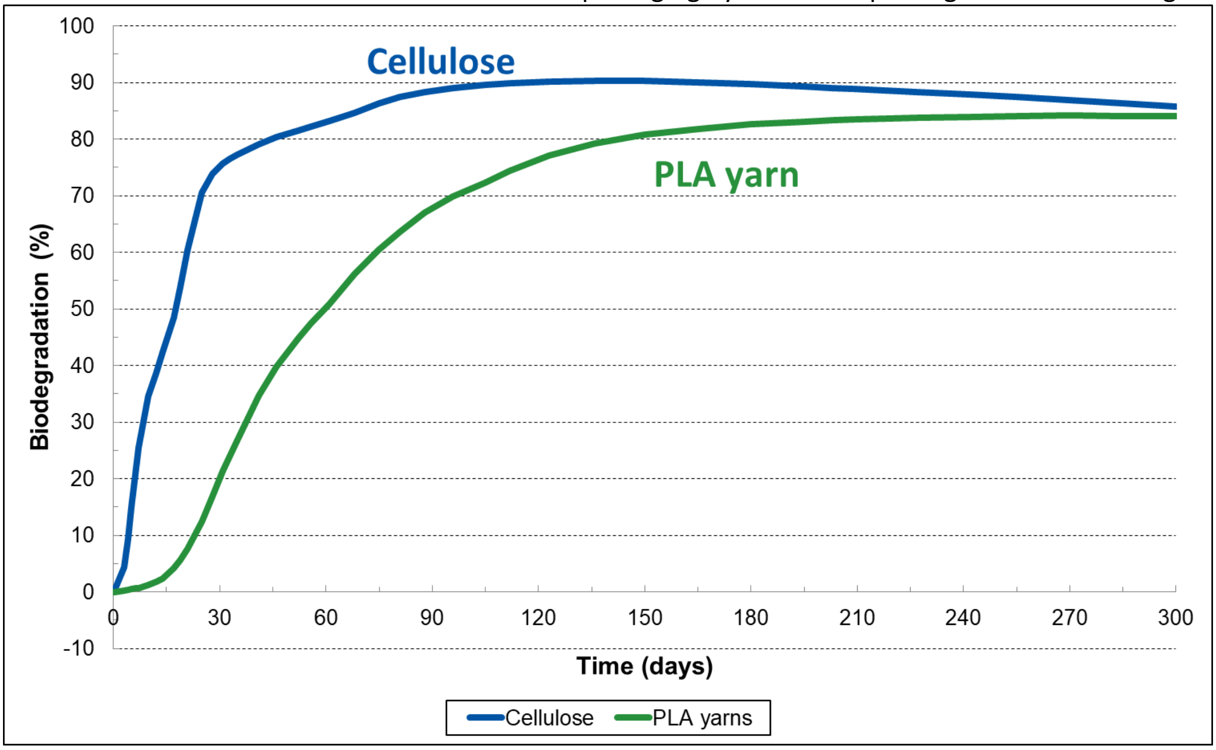


Figure 4: Biodegradation of PLA-based yarn under home composting conditions

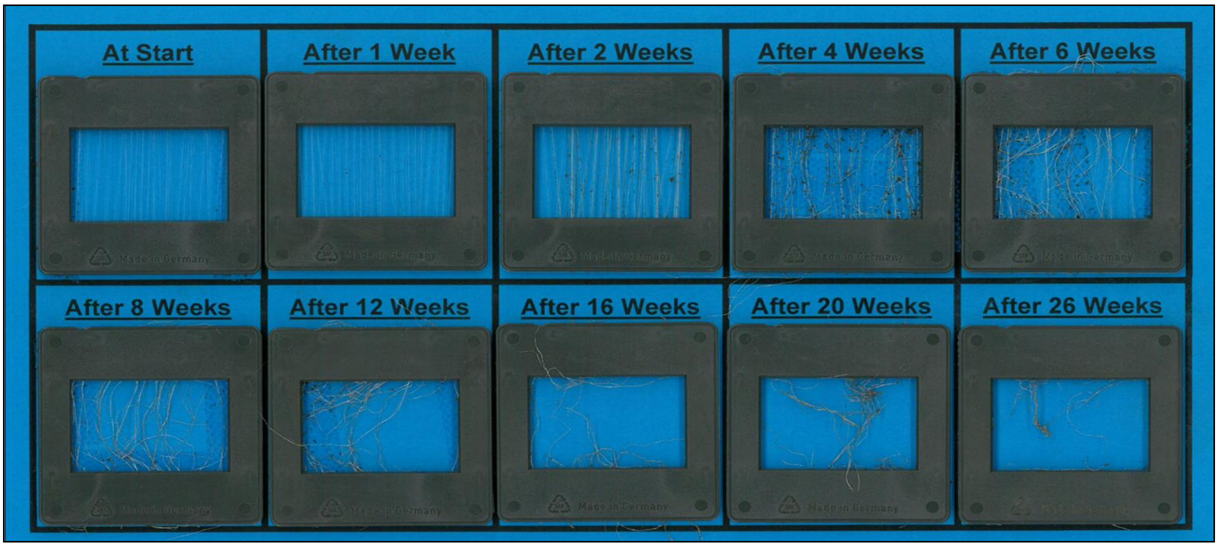


Figure 5: Visual presentation of the evolution of the disintegration of PLA-based yarn in slide frames during the home composting process

Figure 6: Visual presentation of the disintegration of alginate coated PLA-based tea bag after 12 weeks of home composting

1.1 Flexible film and tray

Within the project a Flexible Film Formula N2 (± 54 µm) was developed with PLA as main constituent. Although the film showed complete disintegration withing 26 weeks under home composting conditions (Figure 7), the biodegradation under home composting conditions was insufficient (Figure 8) and seemed to take off only after 1 year. However, it was demonstrated that the flexible film was industrially compostable.

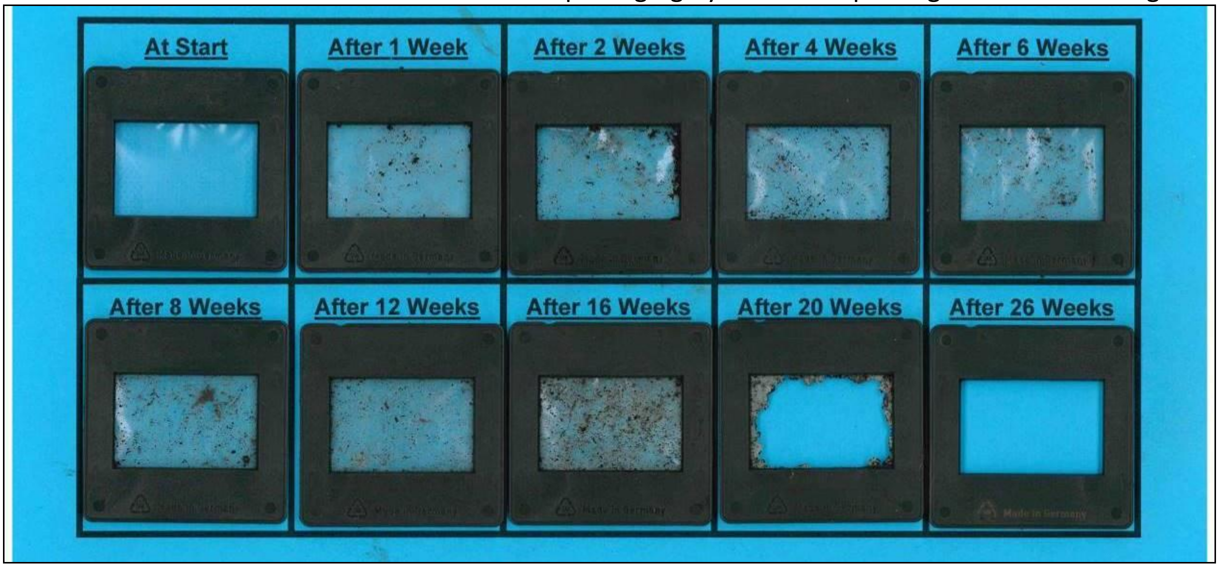


Figure 7: Visual presentation of the evolution of the disintegration of test material Flexible Film Formula N2 in slide frames during the home composting process

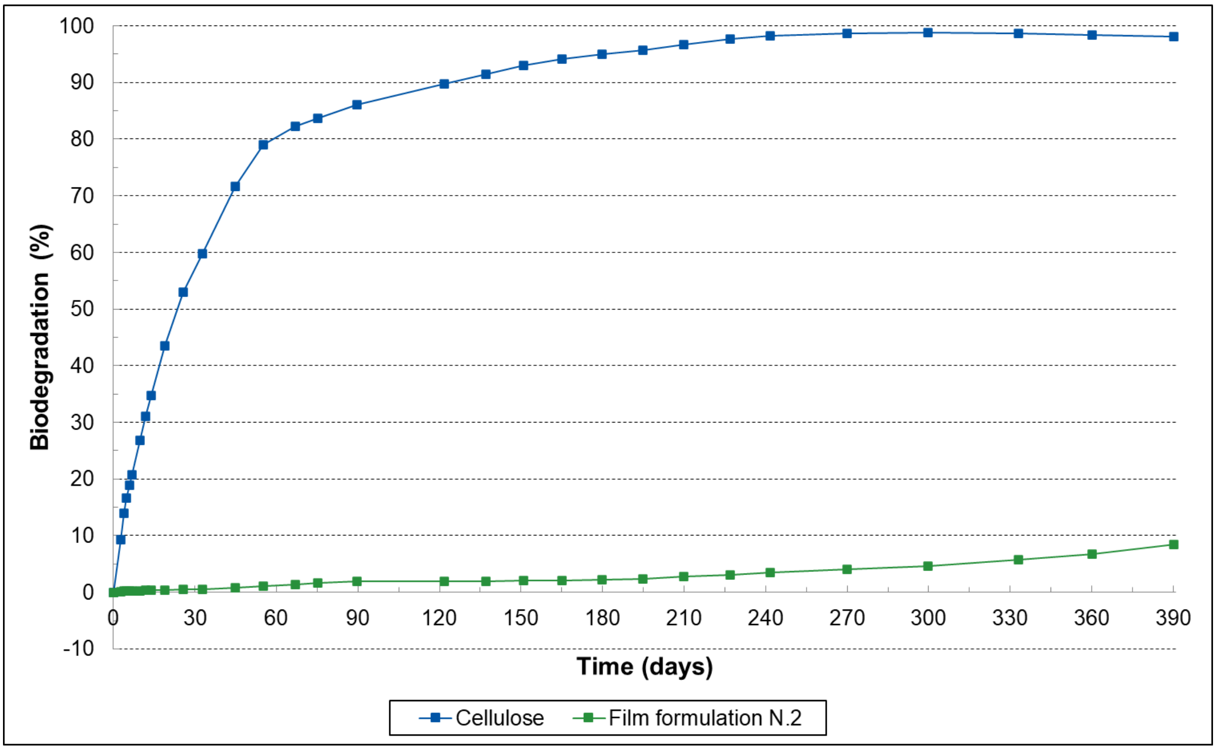


Figure 8: Biodegradation of PLA-based Film formulation N2 under home composting conditions

The developed Tray Formula N1 (± 0.42 mm), also PLA based, fulfilled the requirements on biodegradation and disintegration under home composting conditions (Figure 9 and Figure 10) and is, moreover, also industrially compostable.

The disintegration of the complete tray with film, namely Tray Formula N1 Thermoformed and Thermosealed with Flexible Film Formula N2, in a thickness of ± 0.05 mm (film), ± 0.26 mm (bottom), ± 0.39 mm (edge) was quantitatively evaluated during composting at ambient temperature. The test item (height: 3.2 cm; length: 23.0 cm; width: 15.2 cm) was added as such (with lid sealed on one side of the tray, Figure

11**¡Error! No se encuentra el origen de la referencia.**) in the composting reactor. The test material was mixed with compost inoculum in a 0.5% concentration and incubated at 28°C ± 2°C in the dark. The disintegration of Tray Formula N1 Thermoformed and Thermosealed with Flexible Film Formula N2 proceeded swiftly. Figure 12 shows the tray after 10 weeks of home composting. The product had clearly fallen apart. Already after 18 weeks of composting the tray had completely disappeared, which is much less than the maximum prescribed test duration of 26 weeks. The tray with film reached the disintegration requirement under home composting conditions.

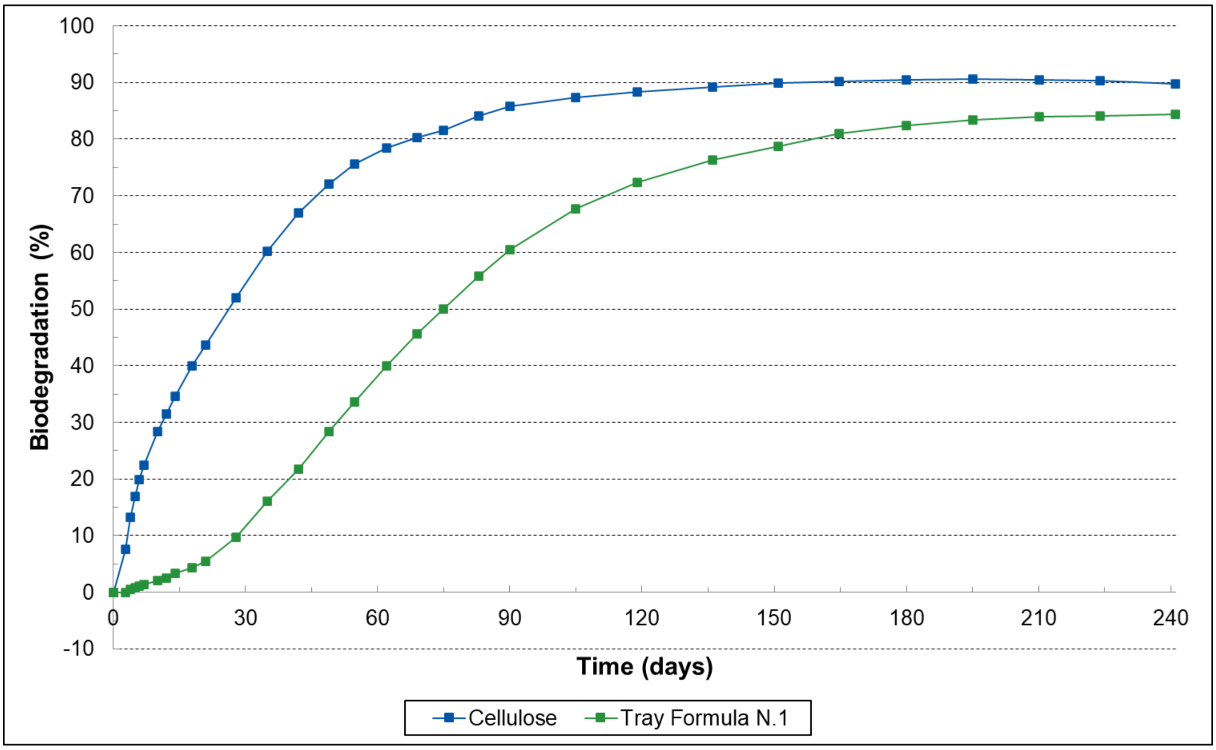


Figure 9: Biodegradation of PLA-based Tray formulation N1 under home composting conditions

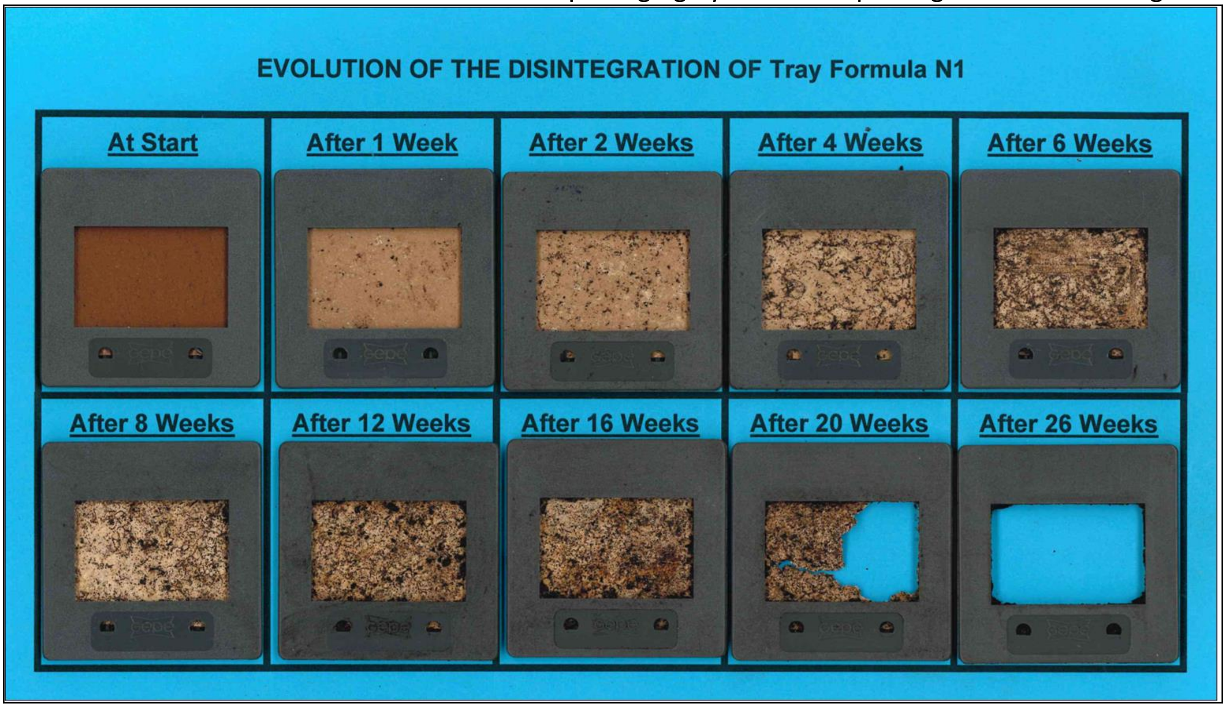


Figure 10: Visual presentation of the evolution of the disintegration of test material Tray Formula N1 in slide frames during the home composting process

Figure 11: Visual presentation of complete tray with film (Tray Formula N1 Thermoformed and Thermosealed with Flexible Film Formula N2), in a thickness of ± 0.05 mm (film), ± 0.26 mm (bottom), ± 0.39 mm (edge)

Figure 12: Visual presentation of the contents of a composting reactor with Tray Formula N1 Thermoformed and Thermosealed with Flexible Film Formula N2, added as such, after 10 weeks of composting at ambient temperature

1.2 Oriented net

Finally, also the within BIONTOP developed oriented net (thickness: ± 0.38 mm), again mainly PLA based, was evaluated for disintegration under home composting conditions (Figure 13). After 16 weeks of composting, the Oriented net was still completely intact (Figure 13. The disintegration seems to proceed too slowly.

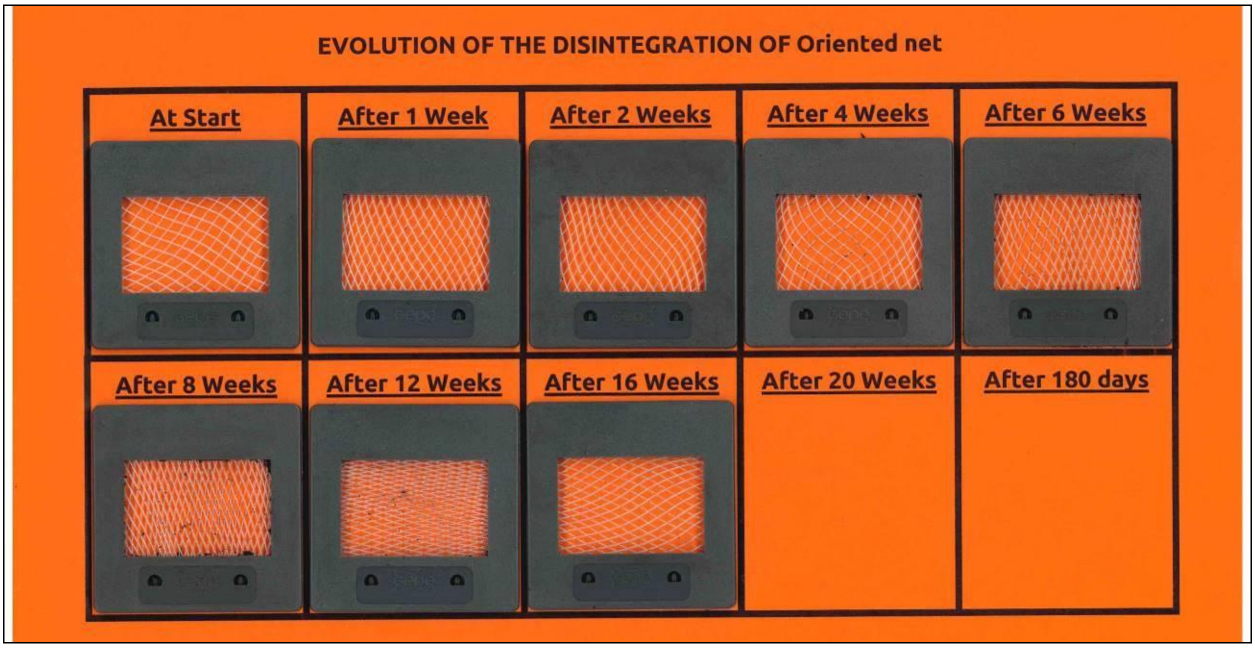


Figure 13: Visual presentation of the evolution of the disintegration of test material Oriented net in slide frames during the home composting process

2. Anaerobic digestion

Organic recycling can be an environmentally end-of-life treatment for products that have the tendency to be ‘contaminated’ with organic matter (e.g. food packaging, agricultural auxiliaries,…). The EU Packaging and Packaging Waste Directive 94/62/EC (amended in 2005/20/EC), currently under revision, defines it as the aerobic treatment (industrial composting) or anaerobic treatment (biogasification) of packaging waste. In the reported trials the products were tested as such (no milling step) to simulate how they would enter in an anaerobic biogasification plant and as such are real case data. In biodegradation testing normally materials are reduced in size (e.g. by milling) which would result in faster biodegradation rates. The teabag was not evaluated under anaerobic conditions as the final formulation was only achieved late in the project and it was not an issue for the end-user.

2.1. Flexible film and tray

Dry, anaerobic mesophilic conditions

The biodegradation and disintegration under dry anaerobic, mesophilic conditions (37°C) was performed on demonstrators Flexible Film Formula N2 (± 54 µm) and Tray Formula N1 (± 0.42 mm) in their final form. The biodegradation results can be found in Figure 14. Cellulose filter paper was taken along as positive reference item. The average retention time in mesophilic biogasification plants is 28 days. After this period test items Flexible Film Formula N2 and Tray Formula N1 showed only a slightly positive biodegradation result. After 28 days an absolute biodegradation of 4.8% ± 1.7% and 12.9% ± 1.8% was measured, respectively. In general, a test item has shown a satisfactory level of biodegradation when 90% absolute or relative biodegradation is reached. This was not the case for test items Flexible Film Formula N2 and Tray Formula N1 within 28 days.

An overview of the visual observations of the degradation of the test items is given in Figure 15, while the calculated disintegration percentage of reference and test items is shown in Table 1. Test item Flexible Film Formula N2 (± 54 µm) showed no disintegration. The slightly negative disintegration results were due to some pollution by remnants of the inoculum still sticking on to the test item. For test item Tray Formula N1 (± 0.42 mm) no signs of disintegration were observed visually after 28 days, although a disintegration percentage of 11.1% ± 0.3% was calculated. Part of the material was degraded, resulting in a decrease in weight.

From these results, it was concluded that Flexible Film Formula N2 (± 54 µm) and Tray Formula N1 (± 0.42 mm) cannot be treated in a dry, mesophilic anaerobic digestion plant.

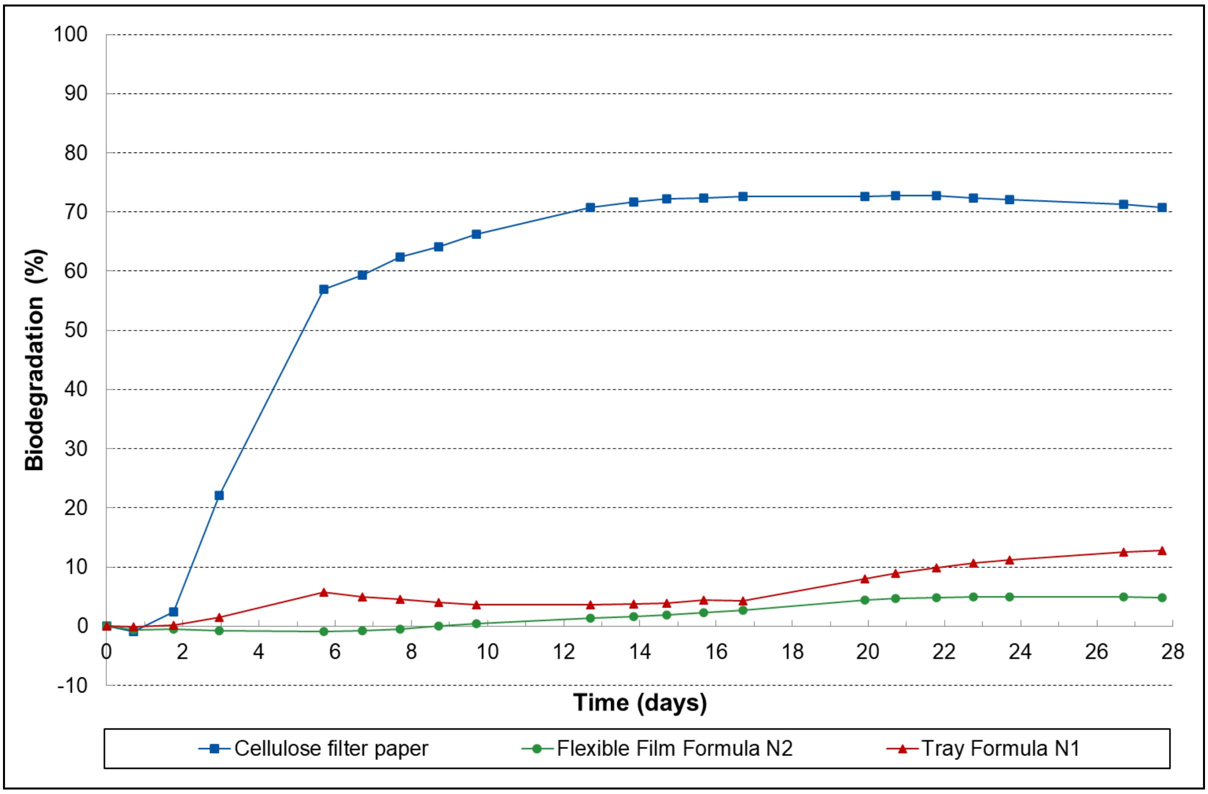


Figure 14: Mesophilic, high-solids anaerobic biodegradation of Flexible Film Formula N2 and Tray Formula N1

Test series	Disintegration (%)		
	Replicate	AVG	SD
Cellulose filter paper	100.0	100.0	0.0
	100.0		
Flexible Film Formula N2 (± 54 µm)	-3.6	-3.8	0.2
	-3.9		
Tray Formula N1 (± 0.42 mm)	10.9	11.1	0.3
	11.3		

Table 1: Disintegration percentage of reference and test items after 28 days under dry, mesophilic anaerobic conditions

	
Disintegration of cellulose filter paper (RN 2)	Disintegration of cellulose filter paper (RN 6)
	
Disintegration of test item Flexible Film Formula N2 (RN 3)	Disintegration of test item Flexible Film Formula N2 (RN 7)
	
Disintegration of test item Tray Formula N1 (RN 4)	Disintegration of test item Tray Formula N1 (RN 8)

Figure 15: Visual representation of reference and test items after 28 days of incubation under dry, anaerobic mesophilic conditions

Dry, anaerobic thermophilic conditions

Furthermore, the anaerobic biodegradation and disintegration of Flexible Film Formula N2 (± 54 µm) and Tray Formula N1 (± 0.42 mm) was evaluated under dry, thermophilic conditions (52°C). The test lasted initially 21 days, which is the average retention time in thermophilic high-solids digestion plants, to determine the disintegration at that point. Afterwards, the test items were re-introduced and the test was restarted to investigate the further progress of degradation.

The biodegradation results can be found in Table 2 and Figure 16. After 21 days, only limited biodegradation was noticed for test items Flexible Film Formula N2 and Tray Formula N1 with a biodegradation of 3.8% and 8.9%, respectively. No breakthrough in disintegration was observed. After the restart, the biodegradation rate clearly increased. After 113 days of testing an absolute biodegradation percentage of 52.8% ± 28.9% and 65.8% ± 8.2% was measured for test items Flexible Film Formula N2 and Tray Formula N1, respectively.

In general, a test item has shown a satisfactory level of biodegradation when 90% absolute or relative biodegradation is reached. This was not (yet) the case for test items Flexible Film Formula N2 and Tray Formula N1 after 113 days, although biodegradation is still proceeding. For test item Flexible Film Formula N2 there was one replicate low in biodegradation, which is holding back the average biodegradation level significantly, while for the other replicate an absolute biodegradation of 71.8% has been measured.

An overview of the visual observations of the different test items after 21 days is given in Figure 17, while the calculated disintegration percentage of reference and test items is shown in Table 3. Both test items showed only limited disintegration. After 21 days, a disintegration percentage of 2.7% ± 22.1% (Flexible Film Formula N2) and 5.1% ± 0.3% (Tray Formula N1) was calculated. Note that the reactor of Flexible Film Formula N2 with negative disintegration after 21 days was the replicate that was lagging behind in biodegradation.

Although some biodegradation was established, the rate is insufficient for treating the products in a dry, anaerobic thermophilic digestion plant. However, these “dry” digestion plants have often a post-composting phase, during which these materials can degrade.

Test series	Average C_{input} (g)	Average $C_{gaseous}$ (g)	Biodegradation (%)		
			AVG	SD	REL
Cellulose filter paper	6.2	5.3	89.0	7.2	100.0
Flexible Film Formula N2	8.2	2.8	52.8	28.9	59.3
Tray Formula N1	7.8	3.0	65.8	8.2	73.9

Table 2: Thermophilic, high-solids anaerobic biodegradation percentages after 113 days

Test series	Disintegration (%)		
	Replicate	AVG	SD
Cellulose filter paper	100.0	100.0	0.0
	100.0		
Flexible Film Formula N2 (± 54 µm)	-13.0	2.7	22.1
	18.3		
Tray Formula N1 (± 0.42 mm)	5.3	5.1	0.3
	4.9		

Table 3: Disintegration percentage of reference and test items after 21 days of incubation under dry, anaerobic thermophilic conditions

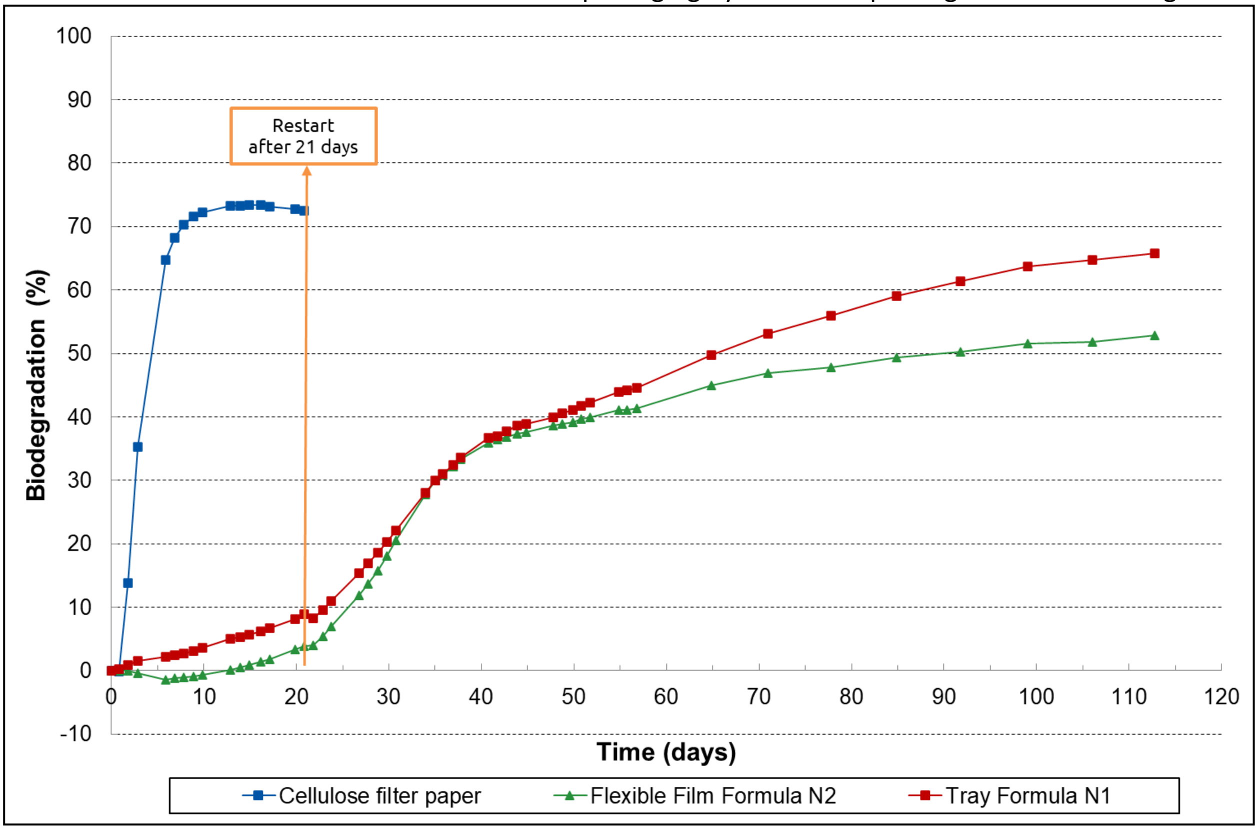
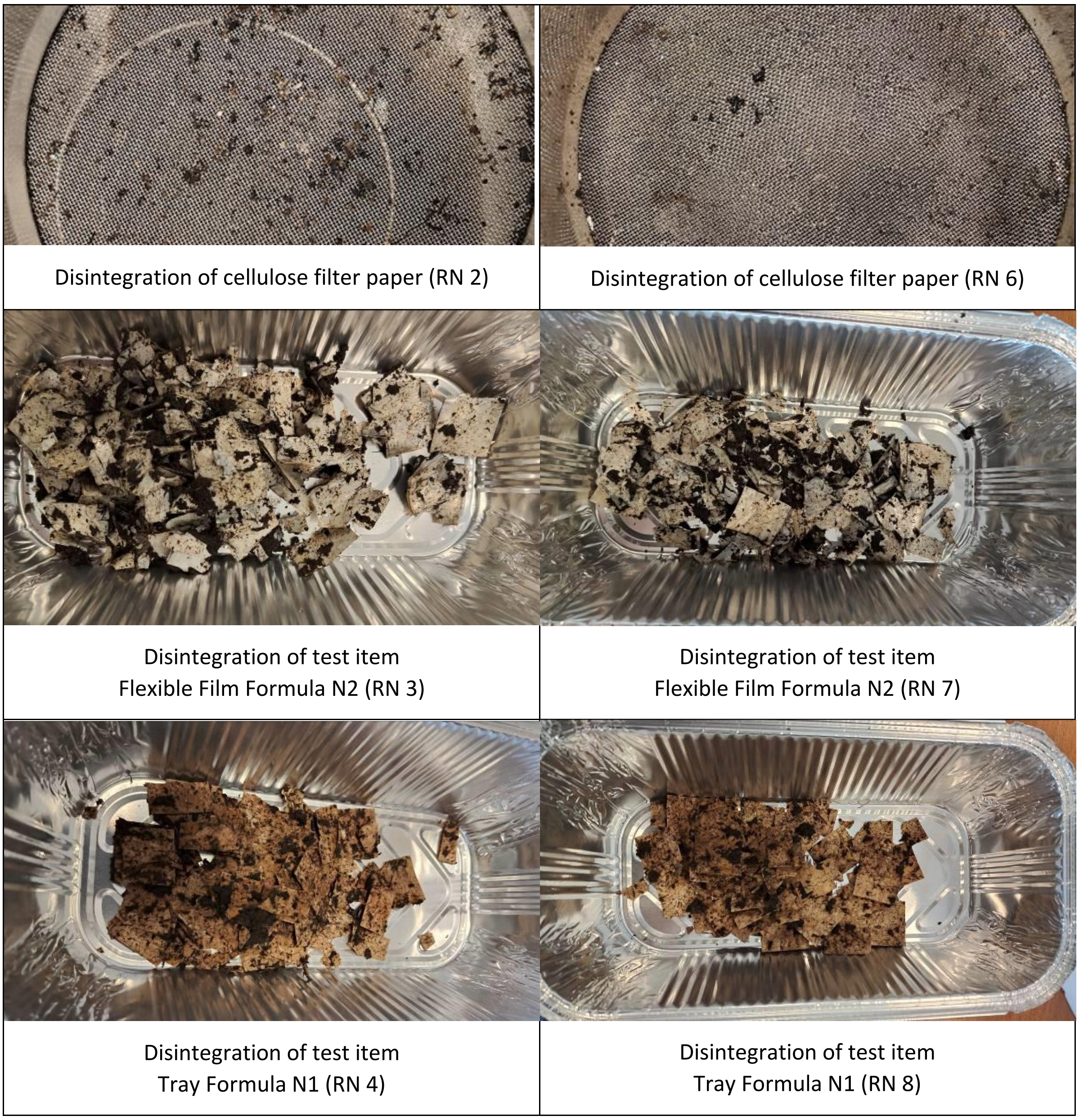


Figure 16: Thermophilic, high-solids anaerobic biodegradation of Flexible Film Formula N2 and Tray Formula N1



Disintegration of cellulose filter paper (RN 2)

Disintegration of cellulose filter paper (RN 6)

Disintegration of test item Flexible Film Formula N2 (RN 3)

Disintegration of test item Flexible Film Formula N2 (RN 7)

Disintegration of test item Tray Formula N1 (RN 4)

Disintegration of test item Tray Formula N1 (RN 8)

Figure 17: Visual representation of reference and test items after 21 days of incubation under dry, anaerobic thermophilic conditions

2.2. Oriented net

An anaerobic biodegradation and disintegration test under mesophilic conditions (37°C) was performed on Oriented net (± 0.38 mm). Again the material was tested as such. The biodegradation results can be found in Figure 18. After 28 days, no significant biodegradation or disintegration was noticed for test item Oriented net. Therefore, it was decided to continue the test beyond 28 days without determination of the disintegration. After 56 days still no significant increase in biodegradation was observed. An absolute biodegradation of 5.7% was measured. Furthermore, no disintegration had yet occurred and consequently the oriented net cannot be treated in a mesophilic biogasfication plant. Thermophilic conditions were not investigated as focus of the project was on degradation at mild temperatures. However, it was demonstrated that the oriented net (± 0.38 mm) was industrially compostable.

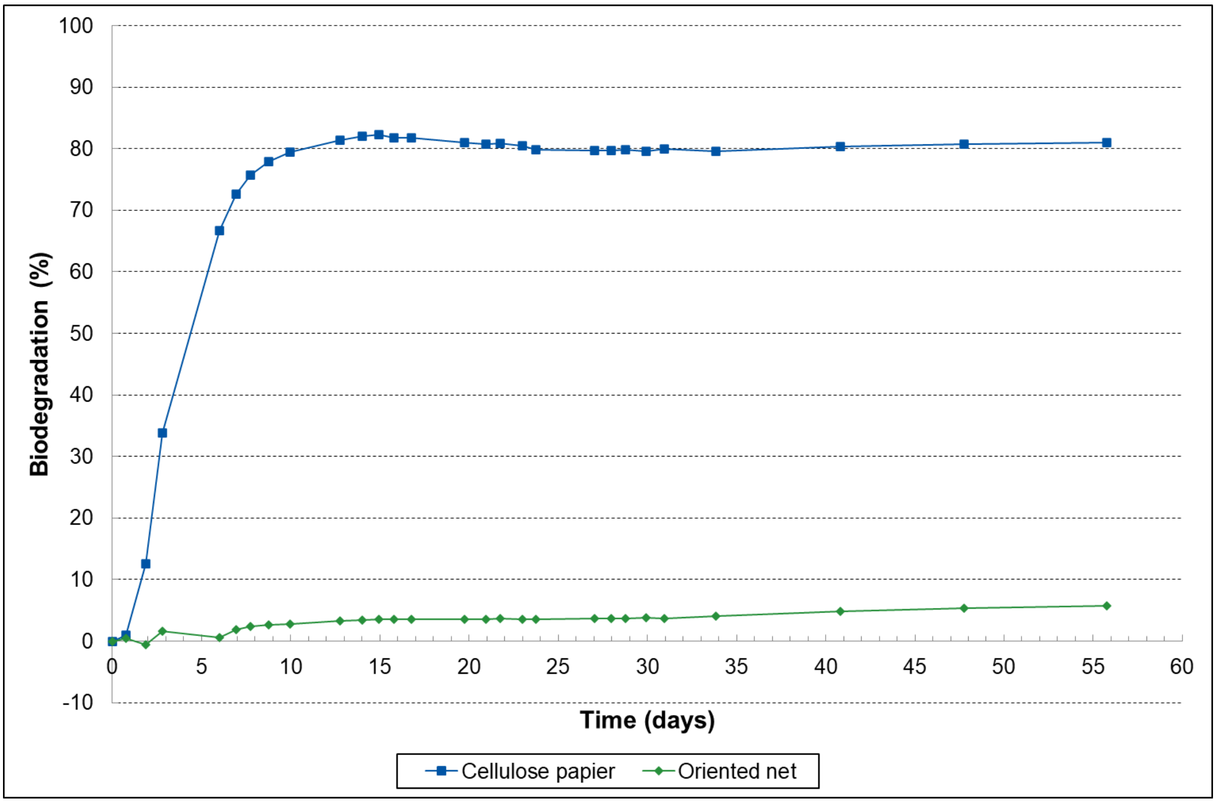


Figure 18: Anaerobic biodegradation of Oriented net under dry, mesophilic conditions

Figure 19: Visual representation of Oriented net after 56 days of dry, anaerobic mesophilic conditions

3. Conclusions

The compostable tea bags, films, trays and food nets were found to have higher impacts on the environmental impact categories of Damage to Resources, Ecosystems and Human health than their reference systems. However, these high impacts were mainly caused by the production stage rather than the end-of-life stage. One exception are the coated BIONTOP tea bags, which were found to have lower impacts than the reference PET-tea bag with plastic secondary packaging. The production of the BIONTOP copolymer, which is used in the films, nets and trays, should be optimized thereby decreasing the electricity consumption required for its production. In addition, the biopolymers and compostable fossil-based polymers which are also used, next to PLA, in the formulation of the demonstrators should also be further optimized in terms of production, although this activity is outside of the scope of the BIONTOP project. It can be summarized that while the BIONTOP demonstrators show additional functionality and processability of PLA, thereby unlocking new product types that can be produced, the current production of the additional materials in the product formulations requires further optimization to be able to achieve environmental impacts as low or lower than the reference systems. Across all investigated demonstrators, the tea bags, whether uncoated or coated, appear to have the most promising results.

The within BIONTOP developed tea bag yarn and tray (± 0.42 mm), based on PLA, are home compostable. However, the film and oriented net could not demonstrate sufficient degradation under these conditions. None of the developed demonstrators (the yarn was not evaluated under these conditions, but a similar behaviour was expected) showed sufficient degradation under anaerobic conditions. They cannot be treated in biogasification plants. However, organic recycling via industrial composting is an option for all products.