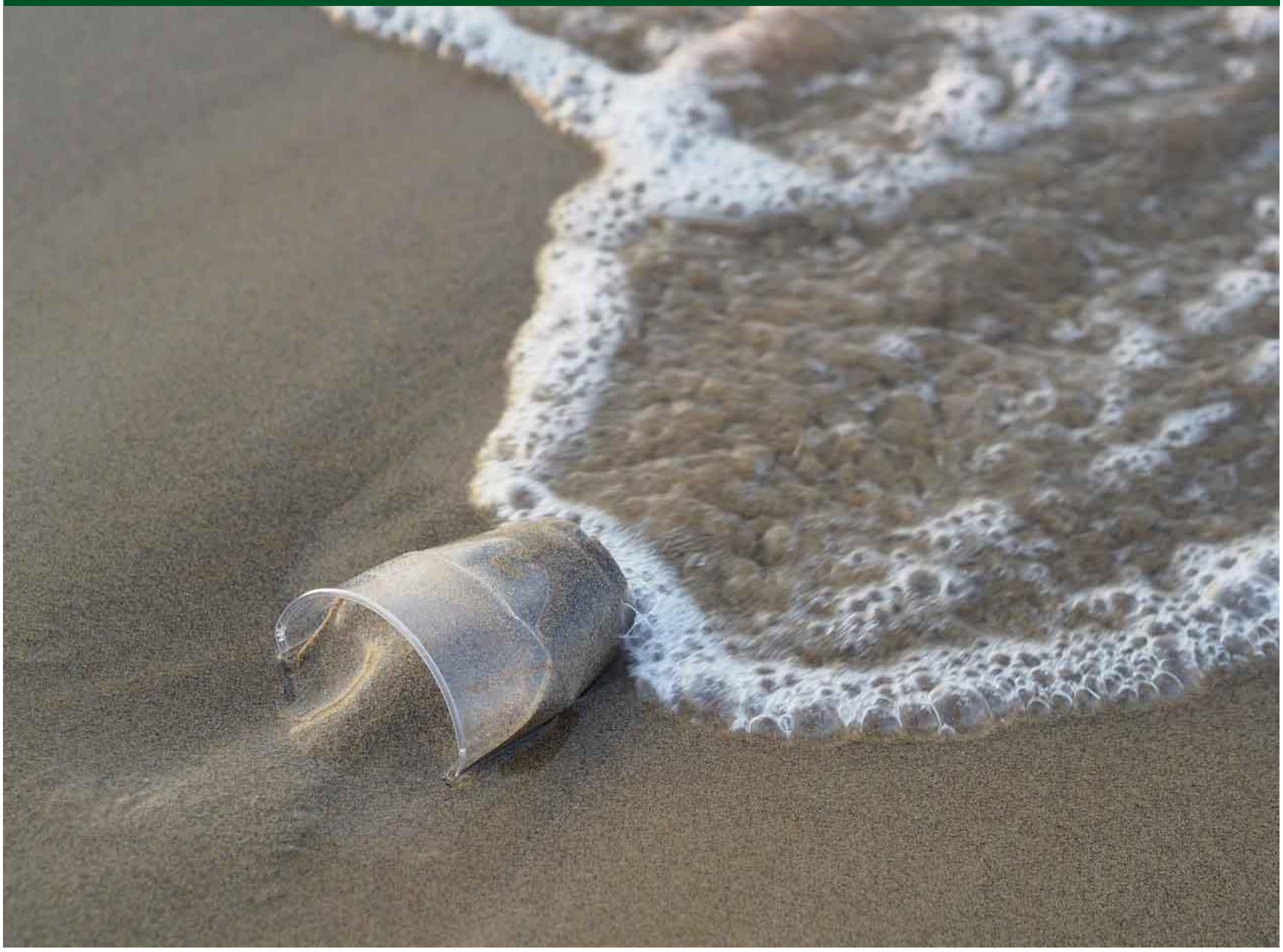
Norwegian Institute for Sustainability Research

Integration of plastic littering in LCA methodology and eco-design tips for the avoidance of littering



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Summary

This report is a part of the DGRADE project, funded by the Norwegian Research Council and Handelens Miljøfond. It presents the status of ongoing development of the LCA methodology with respect to plastic littering issues and how plastic products can be eco-designed for the avoidance of littering.

This report first summarises knowledge regarding littering, the reasons for it and its consequences. Thereafter, the inclusion of littering within the current LCA methodology and on-going work is described. Finally, a summarised literature review and synopses of research into the littered environment is presented, laying the foundation of eco-design tips for singe use plastic products for the avoidance of littering. The literature review comprises issues such as the amount, composition and location of the litter; research on the litterer, including social, demographic and behavioural factors; and research concerning littered items with reference such as size, form or design, which might influence littering. The literature review forms the basis for identifying independent considerations with respect to the littering potential of a specific item or product group.

The report concludes with suggestions, pointers and advice concerning eco-design, as a contribution to the work on the reduction of littering of single use plastic articles. These suggestions do not apply solely to single use articles and can be relevant in the case of many other product types.

Contents

1 Introduction

There is an increasing interest in plastics, both as a resource and as a pollutant. Although a lot of emphasis is placed on recycling, the use of recycled plastics is still low in Europe. In this context, climate change and environmental concerns have boosted the development of various types of biodegradable plastics. The use of biodegradable plastics spans from disposable containers for food/drink, serviceware and wipes, via waste bags for organic waste collected for biogas production, to agricultural films used to cover soil during vegetable production. Waste and recycling companies are poorly prepared for such a transition, as is the public, which is likely to struggle in keeping a profusion of products and their waste separation apart. In addition, biodegradable plastics may not degrade so quickly and completely in a non-industrial setting as their name might suggest; and the label may mislead people, leading to enhanced littering.

The DGRADE project, funded by the Norwegian Research Council and Handelens Miljøfond, was established in 2019. The outcome and impacts from the project are described as:

- Determining if biodegradable plastics are truly and fully degraded when encountering realistic end-of-life conditions in cold climatic regions like Norway, as opposed to accumulation of macro- or microplastics remaining in soil/compost, causing environmental damage and public concern.
- Determining to what extent intended end-of-life treatments leak biodegradable/compostable plastics to the environment.
- Describing the environmental costs/benefits of biodegradable plastics and assess whether they represent materials which align with circular economy.
- Provide the recycling and composting sector with the information needed to make sound decisions on questions regarding biodegradable materials.
- Provide farmers with advice on which type of biodegradable plastic products to use for specific purposes and conditions and which costs/benefits are associated with the available options, including environmental impact at end-of-life.

This report is a part of Task 4.3 under Work Package 4 (Life cycle Assessment) in the project: Follow ongoing research on development of LCA methodology to include plastic litter.

2 Plastic littering

2.1 Amounts, sources and consequences

Not only is plastic litter unsightly, but the negative consequences of plastic on ecosystems, especially the marine environment, and human health is now recognised as a global problem. In recent years, marine plastic litter in particular has attracted growing attention. Jambeck et al. (2015) estimated that in 2010 between 4.8 and 12.7 million tons of plastic ended up in the sea. Their study also estimated that this quantity will in all probability tripled by 2025. According to Schmidt et al. (2017) 10 of the world's mightiest rivers, of which 8 are to be found in Asia, convey 88-95% of global plastic waste to the sea. Thus approximately 80% of the plastic that ends up in the world's oceans, originates from land based sources, transported there by wind and water, while the remaining 20% arises from sea-based sources (Eunomia, 2016; Lebreton et al., 2012).

Most of the plastic material will remain in the marine environment for centuries, as a result of its chemical stability. Spreading along coastal areas and into the open sea, most of it accumulates on the seabed (Eunomia, 2016; Galgani et al., 2015). It is however difficult to determine the extent, causes and consequences of plastic littering, and it is not easy to quantify the amount of plastic waste constituting a littering problem. The literature and public debate deal for the most part with plastic in the oceans, but plastic littering on land also presents a challenge as it also has the potential to influence organisms and ecosystems.

Littering and poor waste management are also identified in the literature as the primary reasons for plastic ending up in the natural environment. Littering occurs most often in relation to recreational activities, tourism, the fishing industry and shipping, and most often comprises short lived items. Of the total globally produced plastic (8300 million tons) less than 10% has been recycled, and less than 15% incinerated. As a consequence, over 75% has ended up in waste disposal or in the natural environment (Geyer et al. 2017). In addition to this, micro and nanoplastic can be engendered during the production of virgin plastic.

Plastic littering can have many negative consequences. Direct damage to biodiversity is by no means the only negative effect of plastic on the environment. Others include the spreading of viruses and bacteria; the proliferation of alien species; effects on human health; the fact that plastic litter is aesthetically unattractive, and such ramifications as the economic consequences for tourism and shipping. With regard to biodiversity, both micro and macro plastic present a danger to marine organisms, resulting from swallowing, suffocation and the release of toxic substances from plastic molecules (Andrady, 2017; Auta et al., 2017; Gall and Thompson, 2015; Woods et al., 2016; Worm et al., 2017). Nanoplastic poses a potential danger because the particles are capable of penetrating cell membranes in both humans and animals (Andrady, 2017; Auta et al., 2017; Gall and Thompson, 2015; Woods et al., 2016; Worm et al., 2017). The literature shows however that there are, at the time of writing, gaps in the knowledge concerning the effects of plastic on human health.

2.2 Plastic litter in LCA methodology

The implementation of plastic littering in LCA methodology, although significant in enabling the analysis of the complete environmental footprint of plastic, is not currently included. This chapter presents the status of the ongoing development of the methodology.

The Medellin declaration (Sonnemann and Valdivia, 2017), which was launched in 2017 during the international LCA conference in Medellin, Colombia, demanded improved handling of plastic littering in LCA, and challenged researchers and other relevant actors to include the effects of marine plastic littering in LCA. As a response to the declaration a workshop was organised in Brussels in May 2018, which gathered together relevant researchers and experts with the goal of developing LCA methodology in this regard.

The network MarLCA, which is supported by UNEP and FSLCI (Forum for Sustainability through Life Cycle Innovation) was created as a result of this. This research network explores the methodological possibilities and challenges created by the inclusion of the effects of plastic littering in LCA (Strothmann et al., 2018). In the project's first phase, a framework will be developed for plastic emissions in the natural environment. This will include the relevant effects and the fate of macro, micro and nanoplastic (Woods et al., 2016). The project's second phase will coordinate projects that will fill the gaps in research, as well as ensuring that there is no overlap in the work being carried out. The results will also be published during this phase. The final phase of the project will provide a harmonised and consensus-based framework for modes of influence, in addition to identifying methods for the integration of plastic littering (MariLCA, 2019).

In order to calculate environmental impacts in LCA, the emissions must be multiplied by a characterization factor (CF), as follows:

$$\text{Environmental impact} = Emissions * CF$$

An emission must first be classified, meaning that it must be shown which impact category(ies) it affects. All emissions affecting an impact category must then be characterized. As mentioned, can plastic litter lead to several environmental and health impacts. There will thus be a need for different characterization factors for different impacts from plastic waste. One characterization factor will, for example, show whether plastic waste leads to the loss of biodiversity, while another will show the effect on human health and a third will show the effect on resource conservation.

The characterization factor is a factor that reflects the relative contribution of emissions to one environmental impact. For example, how much 1 kg of emissions of a given chemical contributes to ecotoxicity. A CF can be expressed as follows (Rosenbaum et al., 2008):

$$CF = Exposure * Fate * Effect$$

For marine litter, *Exposure* refers to how exposed nature is to litter: for instance, will some species have a high plastic intake, while other species tend to entangle faster in plastic articles rather than ingesting them. *Fate* says something about how plastic litter moves in nature affected by wind, rivers and oceans, as well as how the decomposition process takes place from macroplastic to micro- and nanoparticles. *Effect* refers to the consequences of the emissions, such as the number of disease cases / kg of emission, or the proportion of organisms affected in an ecosystem.

This is illustrated in Figure 1, developed by the MarILCA network (MariLCA, 2020):

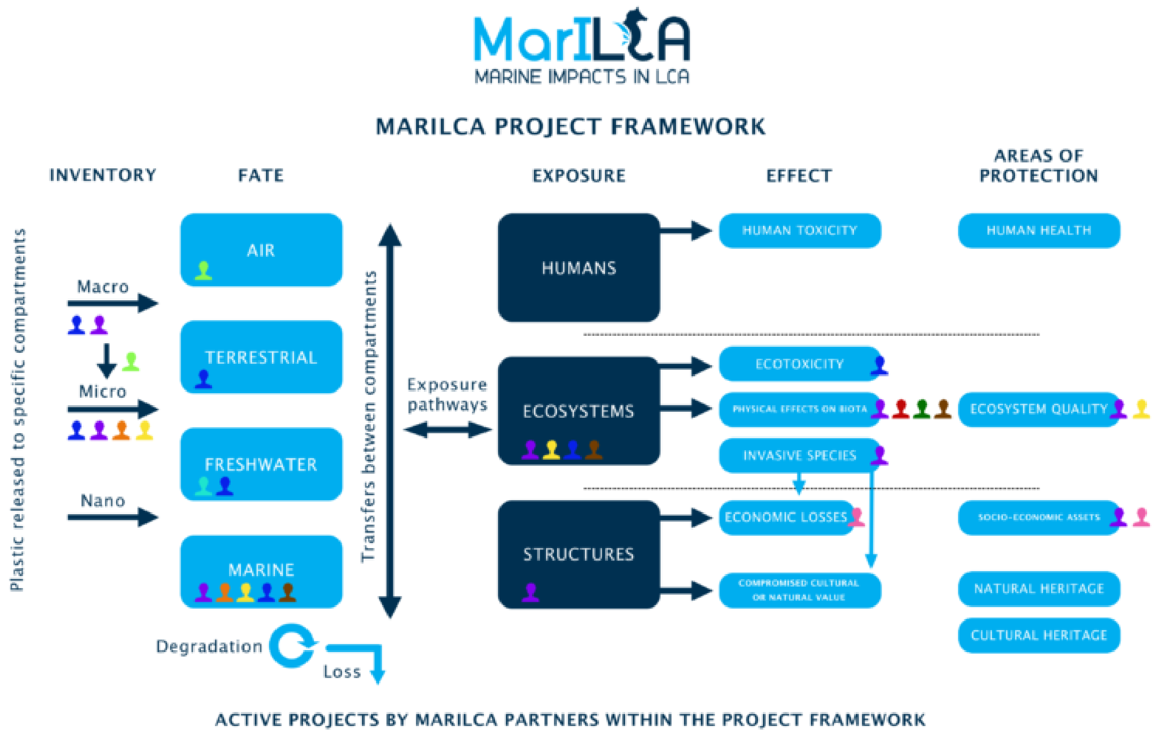

Figure 1: Framework for environmental assessment of plastic litter, developed by MariLCA

The first draft of an effect factor for suffocation by microplastic has already been published in conjunction with the project's first phase (Woods et al. 2019).

The following subchapters present the status of the research front for each of the sections presented above: emission factor, Exposure, Fate and Effect.

2.2.1 Emission factor

Jambeck et al. (2015) provide a general and worldwide inventory for plastics entering the marine environment, for which they suggest two principal sources: mismanaged waste from, for example, uncontrolled landfills or dumped waste, and littering. The former is assumed to be the source of over 90% of global marine plastic and originates in the main from developing countries with densely populated coastlines and a poor waste management infrastructure. The authors estimate a littering rate of 2% of all generated plastic waste, worldwide. In countries such as Norway with a well-developed waste infrastructure, the amount of improperly managed, or dumped waste is insignificant, and littering constitutes therefore the only source of marine plastic. The estimate of 2% covers all plastic. Plastic waste occurring in controlled environments such as in private homes, is far less vulnerable to littering than that which occurs in relatively uncontrolled environments, typically on-the-go products (Roper og Parker (2006); Muñoz-Cadena et al. (2012); UNEP (2018)). If the overall estimate of 2% is correct, the littering rate of on-the-go products ought to be higher than this.

2.2.2 Exposure

No substance or emission contributes to damage as long as no organisms are exposed to these substances or emissions. *Exposure* considers whether organisms or humans are in contact with a substance or emission, such as plastic going astray (Askham, 2011).

If ingestion of the substance or emission can contribute to damage, the exposure is associated with the amount of substance or emission ingested via the food / mouth. If the damage can be linked to the amount of substance or emission inhaled, exposure is associated with the concentration of the substance or emission in the air and how much one inhales.

Regardless of the method of exposure, the term "exposure-intake fraction" is used for organisms, while the term "intake fraction" is used for humans. Parameters such as population density, concentrations in soil / air / water (environmental compartment), and time perspective on the exposure are important for whether the exposure leads to damage to the organism or humans.

2.2.3 Fate factor

Lebreton et al. (2012), and Eunomia (2016) have published several studies on the way in which plastic behaves when it ends up in the natural environment. Depending on their material qualities, varying types of plastic will be transported in different ways and thus accumulate in different places, as illustrated by Andrady (2017) and Galgani et al. (2015).

The existing literature is unfortunately at an early stage and the figures therefore very rough. Jambeck et al. (2015) present a detailed analysis, disaggregated at a national level. It was estimated that, for Norway, approximately 8400 tons of plastic were released into the sea from land-based sources in 2010. This figure was based on the size of the population, the amount of waste generated, the proportion of plastic in that waste and the quality of the waste management system, as well as littering in general.

2.2.4 Effect factor

It has been pointed out that the effect factors ought to be differentiated with regard to the type of influence on the environment: direct damage to biodiversity is not in fact the only negative influence of plastic on the environment. The spread of viruses and bacteria, proliferation of alien species, aesthetics, and negative effects on human health are also influences to be taken into consideration.

Where influence on biodiversity is concerned, the size of the littered items can inflict various forms of damage on an organism. Suffocation is largely caused by macroplastic, while death from swallowing is primarily caused by microplastic (Gall and Thompson, 2015). There is therefore a need for differentiation between the effects of microplastic, macroplastic and nanoplastic, as well as between the varying types of influence on ecosystems: these being chemical, physical and biological. The first refers to potentially damaging additives, which can detach from the polymer, or to substances that can bind to the polymer and which could affect the health of both humans and animals. The differences in physical damage are chiefly influenced by particle size, while biological damage refers to the plastic being a transport medium for various species.

Biological and chemical influences of micro and nanoplastic may already have been included in other effect factors, for impacts such as toxicity and eutrophication. Physical damage is therefore the most significant element not included in current LCA analyses. This is thus an area that requires focus in methodological development (Strothmann et al., 2018).

Woods et al. (2019) present an approximate effect factor for suffocation of marine species (Figure 2). The method combines geographically-differentiated, as well as species-differentiated data: the proportion of species affected by suffocation caused by floating plastic litter is linked to geographically-differentiated data on the density of floating macroplastics. The factor thus calculates the proportion of species that are potentially affected per unit of floating plastic density.

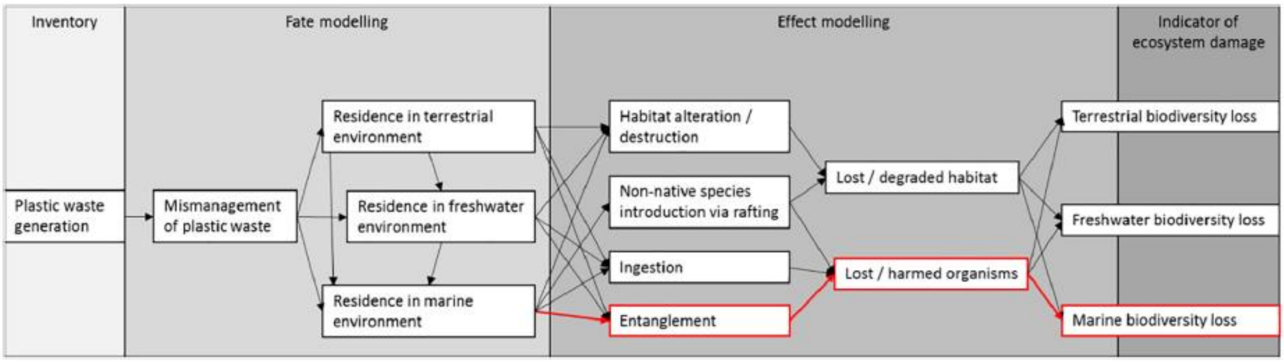

Figure 2: LCIA modelling of plastic littering. Source: Woods et al. (2019)

The environmental categories for marine littering should be developed regionally, as local conditions can have major significance (Strothmann et al., 2018). In addition, there is a need to improve knowledge relating to the time horizon for the breakdown of plastic, and the way in which different accumulation areas in nature influence ecosystems (Woods et al., 2016).

There is still little knowledge with respect to the consequences of plastic litter on human health, organisms and ecosystems, and especially for micro- and nanoplastics. This must be further mapped for relevant environmental impacts caused by the litter (Strothmann et al., 2018). Mapping the dispersion and quantities of plastic litter in the environment (e.g. Jambeck et al., 2015; Lebreton et al., 2012) can in the long term be combined with the effect factors to form a full characterisation factor for ecosystems (Woods et al., 2016). Thus, as well as the development of methodology, there is a need for additional research and statistics, and increased interdisciplinary collaboration in the field.

2.2.5 Likelihood of singe use plastic items littering

To be able to lay the foundation for science-based eco-design tips for avoidance of littering of singe use plastic products, a more in-depth literature study was conducted.

The body of relevant research literature regarding littering of various products can be broken down as follows:

- Research into the littered environment (concerning issues such as quantities, composition and location of the litter)

- Research regarding those who litter (this includes social, demographic and behavioural factors)
- Research on the littered items (such as elements of size, shape and design which could influence littering)

All three categories have direct or indirect significance for laying the foundation for science-based eco-design tips for avoidance of littering of singe use plastic products.

A greater part of the literature concerns the littered environment, through, for example, the measurement of quantities of litter in various parts of the marine environment (beaches, surface water or open sea). These are documented in journals such as, amongst others, the Marine Pollution Bulletin. Some of these studies refer specifically to the Norwegian environment (Falk-Andersson et al. 2019, for example). They are however only of indirect value here: the prevalence of certain types of litter on beaches only indirectly reflects litter rates for specific objects. This type of data becomes more useful when it is combined with other factors, as will be described in more detail below.

Research concerning people who litter has been central to litter research since the 1960s. The results seem to be in line with research on the littered environment. This area of research analyses the social and demographic factors that correlate with littering behaviour, as well as looking at the efficacy of particular interventions for its prevention or reduction. Examples of this would be the location and design of litter bins or signs. The observational studies of littering behaviour included in the research, provide data on the littering rate for different items. Schultz et al. (2013) conducted a large-scale observational study, covering the littering behaviour of almost 10 000 individuals in the USA, across a broad spectrum of outdoor locations. The results showed a littering rate of 17% across a range of items which could be defined as on-the-go items. Other products, such as cigarette butts, were shown to have a very high littering rate.

The most convincing and specific estimates on littering rates found in the literature stem from work carried out on behalf of the EU commission (Elliott et al., 2018) and later adapted to a Norway-specific context (Briedis et al., 2019). These studies are methodologically significantly more extensive and convincing than others. The littering rate for specific items was estimated by creating a link between the occurrence of a particular item in litter and estimates for total littering rates and consumption. These factors were further developed with respect to later waste management (street sweeping), the existence of systems for deposit and return, the incorrect disposal of items into waste water, waste water management, etc.

The European study identified the following single use articles as being the most prevalent: drink bottles, caps and lids, cotton bud sticks, very lightweight plastic bags (such as are used for fruit), balloon sticks, fast food packaging (EPS and non-EPS), beverage cups and lids, straws and stirrers, lightweight plastic carrier bags, wet wipes, sweet wrappers, cutlery, drink cartons and sanitary articles. A littering rate for each category was then calculated. The rates varied from 0.2% to 32% across the different product categories (Table 1).

Table 1: Littering rates for various single use items in Europe (Source: Elliott et al., 2018)

Table 5.3 Littering rates of different items

Item	kg/capita littered	Tonnes littered	Consumption, EU 28, tonnes	SUP littering rate	SUNP littering rate	MU littering rate	Found in Marine Environment (tonnes)
Cigarette filters	0.014	2,416	7,531	32.1%	32.1%	-	121
Drinks bottles	0.37	187,388	2,703,641	6.9%	6.9%	0.0%	9,369
Cotton buds	0.00	1,337	9,547	14.0%	14.0%	0.0%	67
Crisp packets	0.02	4,370	117,045	3.7%	3.7%	-	219
Sweet wrappers	0.00	4,370	138,965	3.1%	3.1%	-	219
Wet wipes	0.00	14,793	47,720	31.0%	31.0%	0.0%	740
Sanitary towels	0.00	25,767	122,698	21.0%	21.0%	0.1%	1,288
Cutlery	0.00	959	206,605	0.46%	0.5%	0.0%	48
Straws	0.005	2,771	88,450	3.1%	3.1%	0.0%	139
Stirrers	0.000	213	139,252	0.2%	0.2%	0.0%	11
Drinks cups and lids	0.16	39,865	302,417	13.2%	13.2%	0.0%	1,993
Food containers	0.11	27,820	544,382	5.1%	5.1%	0.0%	1,391

In Table 1, 'SUP' refers to single use items (of most interest in this context); 'SUNP' refers to single use items made of a material other than plastic; and 'MU' stands for reusable articles. The low littering rates for these last mentioned is due to the unit being 'per use'. They show that these items will in all likelihood be used many times before they reach the waste management stage, and that they present a low littering risk.

Significantly less research exists on littered items. Wever et al. (2010) summarise research that is of interest in this context, and show that the shape, together with certain other product characteristics, is a significant littering factor. The high littering rate of cigarette butts, for instance, is widely recognised in littering studies, yet the underlying reasons are rarely explored. It seems that two factors are principally in play: the small size of the item and a "disgust" factor, relating to picking up the product and disposing of it in the next litter bin. Wever et al. (2010) reveal several factors that appear to influence littering behavior. These include eco-feedback (such as the presence of anti-littering labels) and the reusability/ reclosability of items. Elements that can be influenced by the product's design are not the only important factors. Indirect elements can also affect the potential for the littering of an item. There appears to be very little new research into this subject. That which exists principally concerns packaging and recycling rather than littering.

The following are identified as independent modifying factors in the littering potential of a specific item or product group:

- Eco-feedback or labelling: Documented in Wever et al. (2010). Prominent eco-labelling reduces the littering rate by 40%.
- The likelihood of damage during use: This factor is only discussed qualitatively throughout the literature. When all the other factors are equal, a damaged item is more likely to be littered than one that is undamaged. This increases the littering rate by an expected 20%.
- Disassembly/separation of the item during use: This factor is also unquantified. A specific example is the non-removable ring pull on drink cans; the development of this was partially driven by the high likelihood of littering of the earlier standard removable tabs. It is assumed that there is a high probability that removable parts will be littered, and that this increases the basic littering rate by 10%.
- Reclosability: This factor is specifically described in Wever et al. (2010). As in the factor above, it appears that items that cannot be reclosed are less vulnerable to littering than non-reclosable items. It is assumed that reclosability could reduce the littering rate by 20%.
- Residue on the item after use: This factor reveals the extent to which an item has retained residue after use. It is less likely that care is taken to sort products correctly if they have become especially wet during use or they contain food residue. It is therefore more likely that this factor would increase the littering rate, to an assumed figure of 20%.
- Claimed biodegradability: It seems intuitively reasonable to think that biodegradable products are more vulnerable to littering than those that are not degradable, when all the other factors are unchanged. There is however, very little documentation of this to be found in the research literature. A study by Keep Los Angeles Beautiful (2009) identified a number of archetypes for littering individuals. These included "The Green Crusader" who is generally much less likely to litter, but quite likely to litter biodegradable items. The study assumes that when a product is claimed to be biodegradable, its littering rate increases by 20%.

The above-mentioned points are summarized in Table 2.

Table 2: Factors that can increase or decrease the potential for littering of a plastic product

Factors increasing the littering potential	Factors decreasing the littering potential
High likelihood of damage during use	Eco-feedback or labelling
Residue on the item after use	Reclosability
Claimed biodegradability	
Disassembly/separation of the item during use	

3 Eco-design: suggested pointers and advice

This chapter summarises relevant eco-design pointers and advices for avoiding littering of plastic items. Further tips on the reduction of environmental impacts, with specifications on reusable items and materials are presented. Note that these tips are general and can be applied to other items than plastic products.

Suggestions for the reduction of littering

- Label items with a sorting category for waste management.
- Design items so that they are less likely to be damaged or broken in use, and which are less likely to be disassembled.
- Design items that can easily be recycled or reused.
- Design items that have the least chance of retaining residue after use.
- Apply caution when emphasising an item's degradability when there is little chance that it would in fact degrade in the natural environment under Norwegian conditions.

Suggestions for lowering environmental impact

- Use the smallest quantity of material possible.
- Use materials with a better and well-documented environmental profile.
- Ask suppliers to provide environmental data for the products they are trying to sell – it is important that there is standardised documentation, verified by a third party, such as, for example, EPD or PEF. These are prepared on the basis of one function, which is defined in the rules for the declaration system (the product rules (PR) for EPD, for example). National and international EPD systems (such as EPD Norway, or the EU's PEF system) often have harmonised rules, and comparisons ought therefore to be possible.

Suggestions concerning reusable items

- Reusable items will require a system and infrastructure for reuse. Make sure that this is included in analyses and or comparisons.
- Ask yourself how high the chances are that the item would in fact be reused if it has retained residue during the first phase of use.
- The more often an item is reused, the lower its environmental impact. Ensure that you state a realistic figure for the number of times the item will be reused.
- Important factors relating to environmental impacts from reusable items:
  - The means of transporting reusable items, and distance to the washing facility, have significant influence on the environmental impact.
  - Weight and/or other factors limiting volume during transport to the washing facility have significant influence on the environmental impact.
  - The energy efficiency of the washing process has a significant influence on the environmental impact.

Materials

It is important to note that different materials have varying environmental impacts. The following information presents some general facts in this regard:

- Plastic as a material has a long lifespan. Littering is a problem because it takes so long for littered plastic to degrade in the natural environment.
- Materials produced from biobased sources (cardboard and paper, wood and natural textiles) degrade more easily in the natural environment.
- The manufacture of biobased materials can require extensive land areas. Land use can be associated with negative effects on biodiversity. It will be important to find documentation regarding the origin of the material, and where and how it is grown. Land use changes (both direct and indirect) can dramatically increase a biomaterial's climate impact.
- In the case of cotton, water consumption will, in addition to greenhouse gas emissions, be a major environmental impact.
- Items from recycled materials generally have a lower impact than those produced from virgin materials.
- Request information from the supplier on all the materials in the item. Certain products/materials can contain a high number of additional materials, such as binders, and it is important that these are also taken into consideration.

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