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Plastic leakage of packaging in Life Cycle Assessment – a theoretical framework

Carla Scagnetti[1]*, and *Manuel* Lorenz[1]

[1] University of Stuttgart, Institute for Acoustics and Building Physics IABP, Department Life Cycle Engineering (GaBi). Wankelstr. 5, 70563 Stuttgart, Germany.

Abstract. The proposed theoretical framework explores how packaging could be assessed from gate-to-grave including the probability to become litter. A growing number of studies have confirmed the omnipresence of plastic pollution. Likewise, it has been revealed that marine litter is mainly caused by poor or insufficient waste management. In this line, the environmental impact of packaging have gained much attention due to significant increase in public awareness. Packaging is often designed for single-use and rapidly transforms into waste after a short life-time. Life Cycle Assessment (LCA) practitioners who assess packaging will need a framework to determine the probability and percentage of packaging material that becomes litter. Currently the available end-of-life scenarios to model the fate of packaging are: recycling, incineration and disposal in landfill. With the estimation of packaging litter potential and littering as an end-of-life scenario, the life cycle inventory flows of pollution can be determined. A framework like this can be adopted by LCA practitioners and decision-makers, it can enable fairer and more realistic LCA comparisons of packaging, and it can help prioritize regulatory action as well as choices within companies.

1 Introduction

The problem of plastic pollution is well documented. Plastic pollution is considered a growing environmental problem, and a large number of studies have confirmed the omnipresence of plastic in the natural environment [1]. Scientific evidence shows that it affects many areas of protection, with impacts to the natural environment, human health and natural resources [2]. However, plastics have a key role in delivering a more sustainable future. Through their unique combination of low-weight, resistance to damage, durability and other fundamental properties, plastic materials can contribute to mitigation of climate change. However, challenges relating to littering and end-of-life (EoL) options for plastic waste, especially packaging waste, must be addressed if the material is supposed to achieve its fullest potential in a circular and resource efficient economy. Likewise, it has been revealed that marine litter is mainly caused by poor or insufficient waste management [3, 4]. In this line, the environmental impact of plastic, and in particular plastic packaging have gained much attention due to significant increase in public awareness [5, 6].

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* Corresponding author: carla.scagnetti@iabp.uni-stuttgart.de

Packaging is the industry with the highest consumption of plastic; due to a short lifetime it consequently has the highest generation of plastic waste [7]. In 2019, packaging waste generated was estimated at 177.4 kg per inhabitant in the EU. The packaging sector is the most significant contributor to plastic waste, generating around 17.8 million tons in Europe, accounting for about 60% of post-consumer plastic waste [7]. A mix of drivers can explain the overall increase, including growing per capita consumption, a shift towards single-use and disposable packaging, growing online sales, and over-packaging of goods [8]. A missing circularity and plastic leakage pathways lead to packaging being released into the environment in an uncontrolled manner.

Public awareness and scientific research in the last couple of years have led to regulations and legislations worldwide [9]. Consequently, there is a trend which focus on the problem linking plastic pollution and the packaging industry.

For the assessment of environmental impacts, there are different methods practiced throughout the planet. The most widely used and comprehensive assessment method is Life Cycle Assessment (LCA). It is standardized in ISO 14040 and ISO 14044 and works with studying all inputs and outputs of mass and energy flows over the whole life cycle, i.e. from raw material acquisition via production and use phase to the final disposal.

In the packaging industry, LCA is used with a theoretical approach, where the focus of investigation is placed on the “planned pathway” of the product or service, excluding unexpected instances, like accidents or “wrong turns” such as littering. Nevertheless, this exclusion is rightfully justified by the minority share of those type of incidents and therefore neglected correctly. However, the awareness and scientific evidence of (especially marine) litter in the past few years highlights the relevance and significance of the inclusion of uncontrolled disposal as realistic EoL scenario. An impact assessment method to account plastic as a pollutant and include marine litter into LCA is currently being developed by the MariLCA group [2] supported by UNEP’s Life Cycle Initiative and the Forum for Sustainability through Life Cycle Innovation [10]. A framework to address this gap in LCA requires the quantification of potential flows of plastic entering different compartments of the environment, and ongoing research on fate, exposure, effects, impact pathways, and impact assessment.

The aim of this paper rises in response to the need of life cycle inventory (LCI), modelling, and data. The main goal of this proposed framework is to identify inventory flows of plastic waste and litter in the packaging industry. Moreover, the goal is to provide a framework for LCA practitioners who assess packaging, to determine the probability and percentage of packaging material that becomes litter. As a result, the product specific LCI of plastic packaging leakage can be determined and entered into LCA models to account for the environmental impact.

In our approach, we understand that the decision for uncontrolled disposal is not taken by the producer or any other clearly defined stakeholder, and therefore the probability or fate of this EoL scenario must be based on the products/packaging’s properties. These properties influence the fate of packaging, and are related not only to the design, but also consumer behaviour, in all cases they are product and country specific.

2 Proposed theoretical framework (under development)

Currently the standardized and available EoL scenarios to model the fate of packaging in LCA are: recycling (material and chemical), incineration (with and without thermal

recovery), and disposal in sanitary landfill. In this line, we propose the establishment of a new EoL scenario: littering.
The inventory is composed of (1) direct generation of litter and (2) indirect generation from waste to litter (recycling, landfill or incineration), as seen in Figure 1.

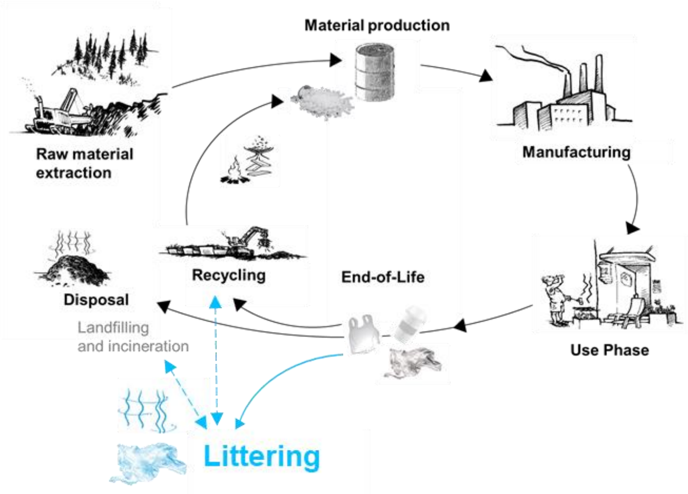

Fig. 1. Life Cycle stages of packaging and proposed new end-of-life scenario. Adapted from: ©IABP

2.1 Example for Germany

Germany has the highest plastic demand per capita in Europe, and the packaging industry consumes 39% of this plastic demand [7]. The treatment of collected plastic packaging waste in Germany differs from the EU average. While 20% of plastic packaging is being directed to landfills in the EU [7], Germany has a ban on this practice and therefore all of the collected waste is redirected to recycling and energy recovery [11]. With this argument, further EoL scenarios are neglected in LCA. However, there is evidence of wild (unregulated) waste disposal in Germany. In addition, single-use packaging is often a source of litter and plastic marine debris [12, 13]. Therefore, this theoretical approach targets the litter and marine litter contribution of plastic packaging in Germany as an example.

According to a study done by Cieplik in 2019, in Germany 53% of the discharge of macroplastic waste into the ocean in Germany can be traced back to packaging [14]. This amounts to 741 kg per year. Another approach to estimate the amount of plastic leakage could be done using the *Plastic Leak Project* (PLP) Guidelines [15]. These guidelines provide generic calculation rules for a plastic leakage assessment and specific calculation rules for macroplastics (e.g. packaging). Likewise, the total plastic leakage is represented by two categories “plastic loss” and “plastic release”, and both are calculated by life cycle stage.

2.1.1 Calculation of litter contribution

The first estimation takes into consideration the amount of plastic packaging waste in Germany. According to literature the non-collected waste in Germany is calculated with the littering factor (LF) of 0.3% [16, 17]. The sum of collected and littered waste equals the generated waste. This is shown in Equation 1 and Equation 2. The calculation of generated waste, is shown in Table 1.

$$Collected\ waste + Littered\ waste = Generated\ waste \quad (1)$$

$$Littered\ waste = (Collected\ waste) \times LF[\%] \quad (2)$$

Table 1. Data for estimation of plastic packaging waste and marine litter contribution

Plastic packaging in Germany	Quantity	Unit	Source
Collected post-consumer waste	3 x 10^6	ton	[7]
Littered factor (LF)	0.3%	-	[17]
Littered waste	9x 10^3	ton	
Generated waste	3.01 x 10^6	ton	
Discharge into the ocean	741	ton	[14]
Marine Litter (ML) contribution	0.025%	-	

$$ML\ contribution = \frac{discharge\ into\ the\ ocean\ [kg]}{generated\ waste\ [kg]} \quad (3)$$

The marine litter contribution is calculated with the discharge into the ocean of post-consumer waste according to literature and using Equation 3, the result is 0.025% of post-consumer plastic waste that is discharged annually into the sea. This percentage is lower than the 0.3% littering factor, due to the loss factors during transport into the oceans, which represent the waste fraction that remains on land. These transport losses account for the plastic fraction deposited in river beds and alluvial plains or collected and disposed of again (e.g. via water treatment plants) [14].

The result of this analysis can be understood as a maximum and a minimum percentage of plastic waste that will end up as litter, and therefore the LCI of littering for the present framework. The estimation of ML rate of 0.025% represents the amount of litter that lands in the ocean, and the 0.3% is the average litter factor, and therefore they represent the minimum and maximum accordingly.

2.1.2 Influence of the packaging design

In addition, research shows that the influence of the plastic packaging design can lead to a higher or lower litter-rate [18]. Packaging material such as paper will usually be disintegrated and metabolised. Other inert packaging (e.g. glass, metal) will likely sink to the sea floor and become sediments [19]. Consequently, for this decision diagram only plastic packaging is analysed. For the estimation of the litter contribution, the flow diagram in Figure 2 is proposed. This will enable the identification of the litter rate as a percentage.

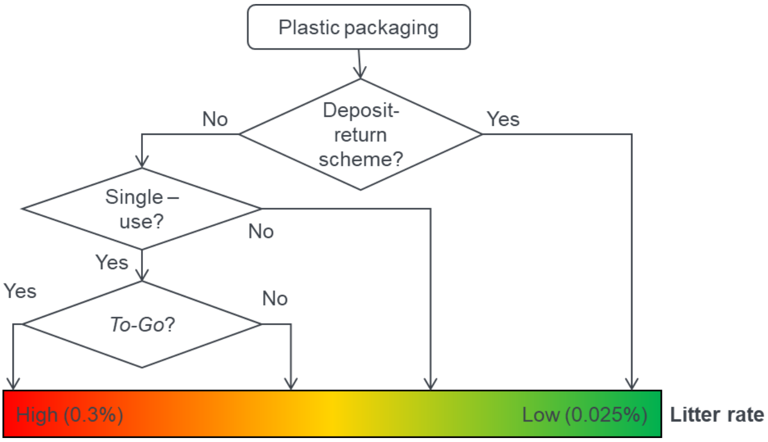

Fig. 2. Flow diagram to identify the litter rate

If the packaging includes a paid deposit-refund scheme the collection is proved to be higher, reducing plastic litter [20]. Moreover, the economic incentive for the consumer (or informal sector) can result in returning the item to collection points, thus avoiding littering [21]. For items that are part of a deposit-refund scheme (e.g. in Germany the *Pfandsystem*) and for reusable packaging, the litter rate is lower than the average. Lastly, packaging designed for on-the-go products is more likely to be found as littered waste [12], research also shows that unforeseen disposal (littering) is higher in an open system (e.g. street food) [22]. Conclusively, this packaging type has the highest litter rate.

3 Results

The litter contribution as the likelihood of a packaging item to become litter in Germany is between 0.3% and 0.025%, which was calculated and explained in the previous section. This probability changes according to the packaging design and use phase. With this estimation of packaging litter potential (or 'litter rates') and littering as an EoL scenario, the **life cycle inventory flows** of plastic leakage can be determined. Moreover, we demonstrate how the probability and percentage of packaging material that becomes litter can be calculated. The calculation is based on design and material of the packaging, the waste management infrastructure (region / country specific), and previous research on litter factors and marine litter contribution. Other factors such as distance to the closest river or coast line should be also considered.

4 Conclusion and outlook

The proposed theoretical framework explores how packaging could be assessed from gate-to-grave with the probability to become litter and includes littering as an EoL scenario in LCA. Marine litter is a recognized environmental issue; however, the focus on the final disposal and waste management practices does not tackle the problem at its source. Plastic pollution starts long before the plastic items have reached the aquatic environments, and likewise should be the solution. In this line, by acknowledging that plastic waste has a litter potential it can support the inclusion of environmental impact in LCA.

Ongoing research on the potential flows of plastic as pollutants entering different compartments of the environment, the associated environmental impacts, the creation, accumulation and toxicity of plastic as a pollutant, and the research being done on impact pathways and impact assessment method, will provide a holistic framework to address this gap in LCA.

The proposed theoretical framework can be adopted by LCA practitioners and decision-makers. It can enable fairer and more realistic LCA comparisons of packaging, and help prioritize regulatory action as well as choices within companies. It can also serve as communication tool with consumers and end-users. It is expected to support LCA of packaging solutions, and addresses the comprehensive aspiration the method has by its nature, to address all life cycle stages and their related impacts to the environment.

In order to move from a theoretical framework to implementation, we identify three further steps. Firstly, an actualization of the inventory values of litter waste is needed. So far these values are taken from literature; however, primary data collection is crucial to quantify the plastic leakage. In addition, it is necessary to include research on consumer behaviour on a regional level, as well as design for life cycle of packaging, and to update the fate factors of littering potential. Second, harmonize the presented approach with the current work in progress of the international MariLCA working group. And for the last step, the implementation should reach inclusion into the marine litter rates and the Circular Footprint Formula of the Product Environmental Footprint Category Rules (PEFCR). The European Commission released the PEFCR as a guidance document and two subsequent drafts for consultation on comparative LCA of alternative feedstock for plastic production, in May 2018 [23]. In line with this framework, the inclusion of littering impacts was discussed and presented in the Stakeholder Consultation Workshop held by the Joint Research Center (JRC) in Brussels in November 2018 [24]. However, the proposal to address littering on an LCI level and account for the share of product potentially ending up as littering has not been implemented yet.

References

1. Ritchie, H. and Roser, M.: Plastic Pollution, Our World in Data (2018).
2. Woods, J. S.; Verones, F.; Jolliet, O.; Vázquez-Rowe, I. and Boulay, A.-M.: A framework for the assessment of marine litter impacts in life cycle impact assessment, Ecological Indicators, **129** (2021), p. 107918.
3. Napper, I. E. and Thompson, R. C.: Plastic Debris in the Marine Environment: History and Future Challenges, Global Challenges, **4** (2020), no. 6, p. 1900081.
4. Kaza, S.: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, Urban Development, The World Bank, Washington, D.C, (2018) https://openknowledge.worldbank.org/bitstream/10986/30317/13/9781464813290.pdf
5. Males, J. and van Aelst, P.: Did the Blue Planet set the Agenda for Plastic Pollution? An Explorative Study on the Influence of a Documentary on the Public, Media and Political Agendas, Environmental Communication (2021), 15:1, pp. 40-54.
6. Heidbreder, L. M.; Steinhorst, J. and Schmitt, M.: Plastic-Free July: An Experimental Study of Limiting and Promoting Factors in Encouraging a Reduction of Single-Use Plastic Consumption, Sustainability, **12** (2020), no. 11, p. 4698.
7. PlasticsEurope Deutschland e. V.: Plastics – the Facts 2019: An analysis of European plastics production, demand and waste data, (2019), accessed November 25, 2021.
8. European Commission: Reducing packaging waste – review of rules. Inception impact assessment, (2020) https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12263-Reducing-packaging-waste-review-of-rules_en.

9. Nielsen, T. D.; Hasselbalch, J.; Holmberg, K. and Stripple, J.: Politics and the plastic crisis: A review throughout the plastic life cycle, Wiley Interdisciplinary Reviews: Energy and Environment, **9** (2020), no. 1, e360.
10. Maga, D.; Thonemann, N.; Strothmann, P. and Sonnemann, G.: How to account for plastic emissions in life cycle inventory analysis?, Resources, Conservation and Recycling, **168** (2021), p. 105331.
11. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: Waste Management in Germany, (2018) – Facts, data, diagrams, 2018, ww.bmu.de/en/publications, accessed November 25, 2021.
12. Chitaka, T. Y. and Blottnitz, H. von: Accumulation and characteristics of plastic debris along five beaches in Cape Town, Marine pollution bulletin, **138** (2019), pp. 451-457.
13. Hanke, G.: Marine Beach Litter in Europe – Top Items at European Commission, Ispra, Italy, (2016), accessed November 25, 2021.
14. Cieplik, S.: Vom Land ins Meer - Modell zur Erfassung landbasierter Kunststoffabfälle, Wasser und Abfall (2019), 1-2.
15. Peano, L., Kounina, A., Magaud, V., Chalumeau, S., Zgola, M., Boucher, J.: Plastic Leak Project: Methodological Guidelines, 2020.
16. Bayerisches Landesamt für Umweltschutz: Umfrage zum Thema "wilde Müllablagerungen": Bayerisches Landesamt für Umweltschutz (LfU): Sonderauswertung zur Abfallbilanz 2001 (2000).
17. Cieplik, S.: Verifizierung des Faktor 0,3%, Frankfurt, 2018.
18. Svanes, E.; Vold, M.; Møller, H.; Pettersen, M. K.; Larsen, H. and Hanssen, O. J.: Sustainable packaging design: a holistic methodology for packaging design, Packaging Technology and Science, **23** (2010), no. 3, pp. 161-175.
19. Doka, G.: A model for waste-specific and climate-specific life cycle inventories of open dumps and unsanitary landfilling of waste, Zurich, Switzerland, 2017, accessed November 25, 2021.
20. Zettl, E. and Roberts, D.: Reducing the input of plastic litter into the ocean around Grenada, Eschborn, Germany, 2015, accessed November 25, 2021.
21. Wilson, D. C.; Velis, C. and Cheeseman, C.: Role of informal sector recycling in waste management in developing countries, Habitat International, **30** (2006), no. 4, pp. 797-808.
22. Ciroth, A. and Kouame, N.: Elementary litter life cycle inventories, approach and application, Poznan, September 2, 2019.
23. Nessi S.; Bulgheroni C., et al.: Comparative LCA of alternative feedstock for plastic production - Draft for consultation Part I / Pat II at Joint Research Center, European Commission (2018).
24. Nessi, S.; Tonini, D., et al.: Draft methodology for comparative LCAs of Plastics at JRC Stakeholder Consultation Workshop, Brussels 29-30 November 2018, (2018)