UNIVERSITÀ DEGLI STUDI DELL'AQUILA

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PROCEDURE FOR EVALUATION CARBON FOOTPRINT PROCEDURE OF SINGLE-USE PLASTIC ITEMS AND THEIR SUBSTITUTION

The procedure developed in partnership with the Department of Industrial and Information Engineering and Economics of the University of L'Aquila wants to highlight the carbon dioxide equivalent emissions that are avoided thanks to reduction, deletion or substitution of single-use plastic items. Reduction or deletion policies have a clear impact on plastic waste direct pollution decrease, but often they also have effect to reduce the lifecycle greenhouse emissions of these components.

The methodology to be referred is the Life Cycle Assessment (LCA, ISO14040), that records every environmental impact of a product (good or service) with the cradle-to-grave approach, from the raw material for its creation are extracted from subsoil, to the end of life management (waste), passing through all the production, assembly, transport, distribution and use phases. When this methodology is applied only to environmental impact related to global warming (greenhouse effect), it is called Carbon Footprint (ISO 14067) because carbon emissions (in the carbon-dioxide form, CO_2) are the main cause of global-scale impact in this category.

Indeed, the developed procedure starts from a meticulous and massive bibliographic research on scientific papers, international reports and publications on LCA and carbon footprint analysis on single-use plastic items. This research allowed to obtain CO_2 equivalent values that are emitted during some products or some products' categories lifecycle. Therefore, this research allowed to group single-use plastic items in some significant categories, for which the dataset would be more complete and especially would be greater for the businesses' interest in adopting PFC certification.

For all the categorized items, all the common plastic materials (PET, PVC, HDPE, LDPE, PP, PS) has been considered. With this approach, it has been possible to realize summarized matrix, where in each product or material category has been identified a kg CO_{2eq}/kg plastic value.

The functional unit, i.e. the reference on which the impact value has been estimated, is in fact the kg of plastic, set from the weight of the individual object. This is by far the most used reference in the literature for this analysis.

The categories identified are those in Table 1. In particular, the category "films" refers to packaging, primary, secondary or tertiary, which wraps many products [1, 2]. The category "garbage bags" includes the various sizes (expressed in volume) of garbage bags [3].

The category "bottles" includes all types of single-use plastic bottles and therefore are characterized by different weights [4, 5]. The category "other packaging" includes all those particular types of packaging, other than films, which have different characteristics and shapes [6, 7]. In addition, the category "detergent bottles" includes single-dose containers for hygiene in general [8, 9]. Finally, the category "crockery" includes all disposable plastic tableware: plates, forks, knives, spoons, mixers, etc., considering a mediated impact between these different product categories [10].

Table 1: products' categories identified

CATEGORIES
Films
Garbage bags
Bottles
Other packaging
Detergent bottles
Other *(general cases and packaging)*
Crockery

Some more general reports have also been identified [11, 12], which have made possible to develop the category defined as "other", which includes all the objects of the most various nature that can be considered disposable. In these reports, the CO_2 emissions related to plastic objects, in different materials, are estimated throughout the product lifecycle: starting from the extraction of petroleum products, to refining process to obtain plastic material, to processing in order to obtain finished products and the end of life, divided into "incineration", "recycling" and "landfill" [13]. The "use" phase is not considered, which has negligible impact compared to the others.

The conducted analysis has also allowed us to evaluate the parameters that most influence the values of equivalent greenhouse gas emissions of single-use plastic products [14]. Among these, the end-of-life management [15], the possible phases of raw materials transport, semi-finished and finished products [1, 16] and the energy mix of electricity production in the geographical context of reference [17] certainly have a strong impact.

The second phase of the assessment allows the analysis of the impact in terms of greenhouse gas emissions, also for the hypotheses of single-use plastics substitution. Three main scenarios have therefore been identified: a) use of products made of compostable plastic materials; (b) use of reusable objects several times; (c) permanent disposal of plastic products by the process reorganization. Only in the latter case, the benefit of CO_2 reduction is total.

In the other two cases, it is necessary to compare the CO_2 value estimated by the life cycle of the compostable plastic object and the multipurpose object with the value of the initial case, obtaining a net benefit [18, 19]. Therefore, the literature analysis on product categories has also been repeated considering biodegradable plastic materials (PLA, PHA, bio-PET, bio-PE, etc. [11, 20]), but also paper, tetrapak, kraftpaper and wood and objects in multi-use material (glass, aluminium) [21].

In this way, the benefit obtained from the replacement of single-use plastic objects and the difference in the carbon footprint with the considered hypotheses of substitution, is clear and allows to direct the

choice of replacement towards opportunities that further reduce the equivalent CO2 associated with the product chain (Figure 1). It is also appropriate to point out that, in the case of multi-use material, the impact is divided into the average number of times of item usage.

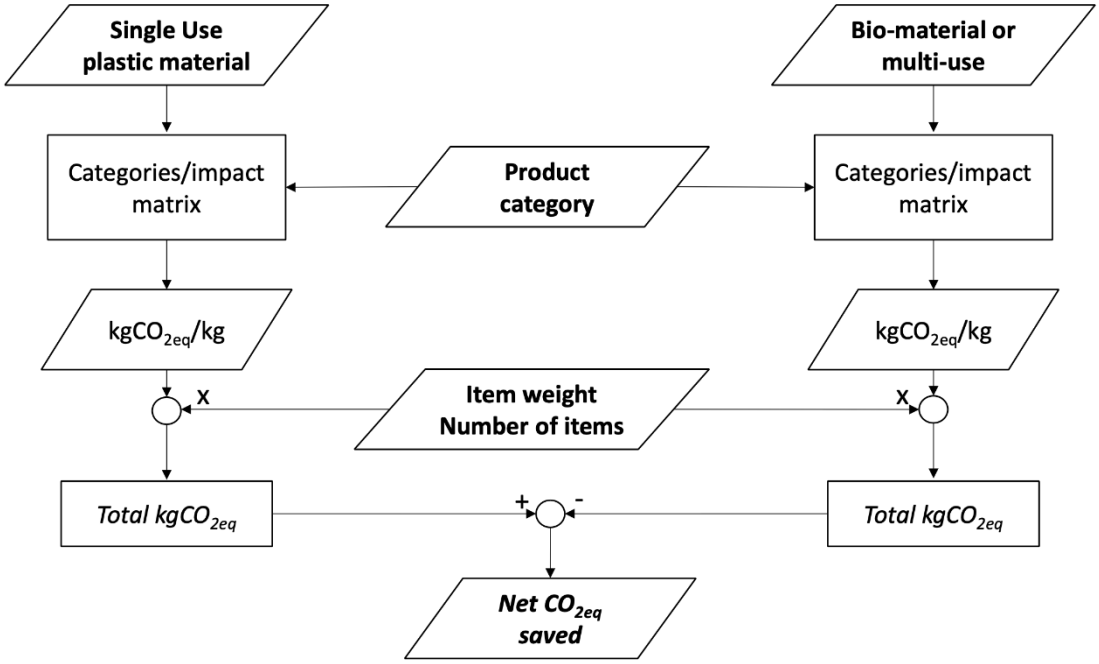

Figure 1: Flowchart of the proposed procedure. In the left part, the section on impact assessment when single-use plastic objects are used, in the right part when these are replaced by compostable materials or multi-use objects. Input data from Plastic Assessment

REFERENCES

1. I. Blanco, C. Ingrao, V. Siracusa, Life-cycle assessment in the polymeric sector: A comprehensive review of application experiences on the Italian scale, Polymers (Basel). 12 (2020) 1–42. https://doi.org/10.3390/POLYM12061212.
2. H. Alhazmi, F.H. Almansour, Z. Aldhafeeri, Plastic waste management: A review of existing life cycle assessment studies, Sustain. 13 (2021) 1–21. https://doi.org/10.3390/su13105340.
3. D. Civancik-Uslu, R. Puig, M. Hauschild, P. Fullana-i-Palmer: Life cycle assessment of carrier bags and development of a littering indicator, Science of the Total Environment 685 (2019) 621–630. https://doi.org/10.1016/j.scitotenv.2019.05.372.
4. Plastic (PET) vs bioplastic (PLA) or refillable aluminium bottles – What is the most sustainable choice for drinking water? A life-cycle (LCA) analysis. Elena Tamburini, Stefania Costa, Daniela Summa, Letizia Battistella, Elisa Anna Fano, Giuseppe Castaldelli Department of Life Sciences and Biotechnology, University of Ferrara, 44121, Ferrara, Italy
5. EXAMINING MATERIAL EVIDENCE THE CARBON FINGERPRINT - Imperial Collage London - Voulvoulis N.(a), Kirkman R.(b), Giakoumis T.(a), Metivier P.(b), Kyle C.(b), Midgley V.(b)

6. K. Verghese, S. Lockrey, S. Clune, D. Sivaraman, Life cycle assessment (LCA) of food and beverage packaging, Woodhead Publishing Limited, 2012. https://doi.org/10.1533/9780857095664.4.380.
7. F. Silvenius, J. Katajajuuri, K. Grönman, Towards Life Cycle Sustainability Management, Towar. Life Cycle Sustain. Manag. (2011) 359–370. https://doi.org/10.1007/978-94-007-1899-9.
8. Revision of European Ecolabel Criteria for Soaps, Shampoos and Hair Conditioners
9. Sonja Leissner, Yvonne Ryan-Fogarty - Challenges and opportunities for reduction of single use plastics in healthcare: A case study of single use infant formula bottles in two Irish maternity hospitals
10. Sustainability Assessment of a Single-Use Plastics Ban. Timo Herberz, Claire Y. Barlow and Matthias Finkbeiner.
11. Eionet Report – ETC/WMGE 2021/3 - Greenhouse gas emissions and natural capital implications of plastics (including biobased plastics) 2021
12. US EPA ARCHIVE - Waste Reduction Model (WARM) and PLASTICS 2015
13. D. Maga, M. Hiebel, V. Aryan, A comparative life cycle assessment of meat trays made of various packaging materials, Sustain. 11 (2019). https://doi.org/10.3390/su11195324.
14. L.S. Dilkes-Hoffman, J.L. Lane, T. Grant, S. Pratt, P.A. Lant, B. Laycock, Environmental impact of biodegradable food packaging when considering food waste, J. Clean. Prod. 180 (2018) 325–334. https://doi.org/10.1016/j.jclepro.2018.01.169.
15. L. Post, Life Cycle Analysis of three polystyrene waste scenarios Biodegradation by mealworms as an alternative to incineration or recycling, (2020).
16. S. Albrecht, P. Brandstetter, T. Beck, P. Fullana-I-Palmer, K. Grönman, M. Baitz, S. Deimling, J. Sandilands, M. Fischer, An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe, Int. J. Life Cycle Assess. 18 (2013) 1549–1567. https://doi.org/10.1007/s11367-013-0590-4.
17. Jiajia Zheng and Sangwon Suh - Strategies to reduce the global carbon footprint of plastics
18. The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe - Summary report
19. George Bishop, David Styles, Piet N.L. Lens - Environmental performance comparison of bioplastics and petrochemical plastics:
20. G.M. Bohlmann, Biodegradable packaging life-cycle assessment, Environ. Prog. 23 (2004) 342–346. https://doi.org/10.1002/ep.10053.
21. G. Cappiello, C. Aversa, A. Genovesi, M. Barletta, Life cycle assessment (LCA) of bio-based packaging solutions for extended shelf-life (ESL) milk, Environ. Sci. Pollut. Res. 29 (2022) 18617–18628. https://doi.org/10.1007/s11356-021-17094-1.

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