Open challenges for Life Cycle Assessment as a decision support tool towards Circular Economy transition

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Abstract: In this article we discuss two open challenges that Life Cycle Assessment (LCA) needs to address in order to confirm its role as decision support tool for a transition to circular economy (CE). The first one regards the role of consumers' in a CE and the need to get a better understanding of consumers' practices. We suggest a combined approach based on LCA and Practice Theory (PT). The second challenge is connected to the urgency of making LCA results more understandable to a broader audience. Different approaches are currently available: use of benchmarks, proxy indicators, single scores and more popular references, but the suitability to a specific context and target audience needs to be further investigated.

1. Introduction

In the first edition of the "Guidelines for Life-Cycle Assessment: A "Code of Practice"" published in 1993 by the Society of Environmental Toxicology and Chemistry (SETAC), Life Cycle Assessment (LCA) was defined as "*one of the tools used to examine the environmental cradle-to-grave consequences of making and using products or providing services"* and it was recognized as "*a powerful and complex tool that should be used properly*" (SETAC, 1993, p.ii). The aim of that publication was to provide guidelines for carrying out and reporting LCA studies "*in a responsible and consistent manner*" and was based on experts´opinion, namely of 50 experts from 13 countries who pooled their knowledge and experience in a 4-day workshop which was held at Sesimbra, Portugal during 31 March - 3 April 1993.

One of the prime objectives of carrying out a LCA that were outlined in the SETAC Code of Practice was *"to provide decision-makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements*" (SETAC, 1993, p.6). Since the early application of LCA in the packaging sector (Hunt and William, 1996), its role as a decision support tool has been consolidated and it has now become an established decision support tool both for private and public organizations and policy makers.

LCA is currently also recognized a key metric for CE, as discussed among others by Schmidt-Rivera et al. (2021), Roos Lindgreen et al (2021), Rigamonti and Mancini (2021) and Brändström & Saidani (2022). According to Peña et al. (2021) "*LCA can support evaluating and comparing the most promising CE strategies and options for improving the environmental performance of society's consumption and production patterns*" (p.216). CE strategies can be classified in four main groups (Bocken et al, 2016, Konietzko et al, 2020): i) narrow, ii) close, iii) slow and iv) regenerate resource flows. LCA has been successfully used to assess the environmental benefits of the first three strategies. There are indeed examples of using LCA to

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assess more resource efficient solutions for single-use plastic products (UNEP, 2021) and in the waste management sector (Laurent et al. 2014). Challenges exists when applaying LCA to assess "closing loops" strategies, typically recycling as described by Niero & Olsen (2016) and Sazdovski et al (2021). More extensive applications can be found in relation to "slowing" loops strategies, such as reuse of e.g. clothes (Farrant et al. 2010), refurbishment e.g. in the case of electric vehicles batteries (Schulz-Moenninghoff et al, 2021), remanufacturing e.g. in the medical equipment sector (Schulte et al, 2021). More recent is the recognition of the use of LCA in the context of regenerative solutions and practical applications.

According to Peña et al. (2021) *"LCA allows to understand and evaluate whether the claimed environmental benefits of CE solutions can be achieved and to what extent, and which are the most critical processes and aspects that needs to be properly managed."*(p.216). However in order to fully exploit the decision support potential of LCA in a CE context there are some challenges that need to be overcome. In this article we will address two of these challenges that in our opinion deserve urgent attention. Our analysis does not aim to be exhaustive, but it aims to stimulate a discussion on which are the challenges that needs to be addressed from both a methodological and operational point of view to make sure LCA will continue to prosper and gain further credibility as environmental sustainability assessment methodology in the next 30 years. In this way we aim to contribute to the on-going discussion on the benefits of using LCA as a key metric for CE micro level assessment (Roos Lindgreen et al., 2021, Rigamonti and Mancini, 2021) and more broadly on the challenges that should be tackled for the implementation of a sustainable CE (Leipold et al. 2023).

For each of the two challenges identified we will first explain what the issue is, then we will propose a solution on how it can be tackled and finally we will outline the implications for the LCA methodology and which are the phases of the LCA methodological framework that will be affected. A summary of the elements discussed in this paper is reported in Table 1.

Challenge	How is it currently addressed	Proposal for future development	Phases of the LCA methodology affected
1.Understanding consumers' practices	Behavioural science	Combining LCA with Practice Theory (PT)	Goal and scope definition; LCI; interpretation
2.Improving communication of LCA results	Benchmark; use of proxy indicators; single score; conversion to popular references	Test different ways of translating LCA results to consumers including users' involvement	Interpretation

Table 1. List of open challenges in relation to the use of LCA in a CE transition discussed in this paper; PT = Practice Theory, LCI = Life Cycle Inventory.

2. Challenge n.1: getting a better understanding of consumers´practices

This section first describes the challenges in addressing consumers' role in a CE (section 2.1) and then introduces the proposal a combined approach based on the integration of LCA and Practice Theory (PT) (section 2.2).

2.1 The issue: consumers' role in a CE

The role of consumers is essential for the success of several CE strategies (Camacho-Otero et al., 2018; Shevchenko et al., 2023). Consumers can choose products based on their recycled

content or durability, or they can influence the overall environmental footprint by adopting the right behaviour during the use phase. However, there are studies showing that there is still a gap between consumers´ perception of the environmental sustainability and the actual LCA results, e.g. Boesen et al. (2019), Steenis et al. (2017). A pivotal action is to provide to consumers trustworthy information in order to guide their consumption choices towards more circular practices, e.g. Testa et al. (2020), Testa et al. (2021).

To improve the modelling of the use phase in LCA, it has been suggested to combine LCA with other disciplines addressing consumers´ behaviour, such as behavioral science (Polizzi di Sorrentino et al., 2016), but more recent studies have highlighted the potential of Practice Theory (PT) in relation to the assessment of circular consumer practices, e.g. Rabiu and Jaeger-Erben (2022) and in combination with LCA (Niero et al. 2021, Suski et al.2021).

PT represents a family of multiple theories of practice that focuses on understanding the social dimensions of 'what people do'. For PT it is important to explore the interconnectedness of meanings (e.g., ideas about a good meal), materials (e.g., food) and skills (e.g., how to prepare a good meal) when studying practices that generate consumption dynamics (Shove et al., 2012).

2.2 Proposal: combined application of LCA and PT

An example of combined procedure to apply LCA and PT has been developed by Truong and Nicot (2022). They investigated how PT can improve the modelling of the use phase in LCA in the context of reusable packaging solutions for takeaway food, specifically via a comparison of single-use *vs* reusable sushi trays in the city of Copenhagen (DK). The application of the framework, reported in Figure 1, will be illustrated through the abovementioned case study.

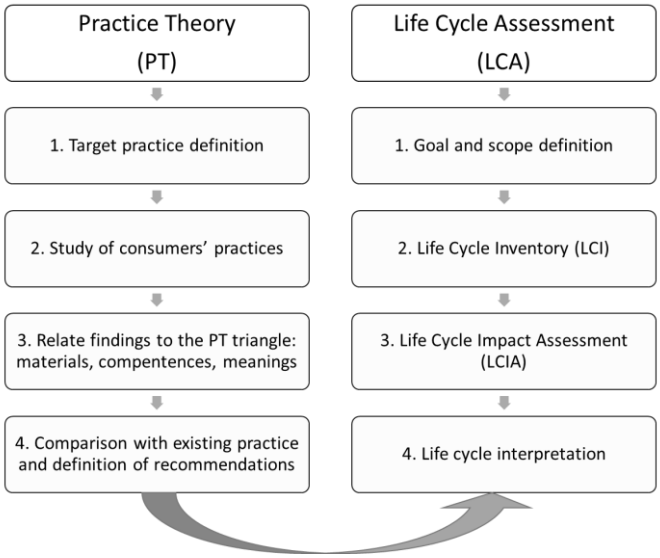

Figure 1. Illustration of the suggested combined LCA-PT analysis based Truong and Nicot (2022).

The first step is the "definition" step, which from the PT perspective consists in the definition of the target practice (i.e. doing takeaway) based on the analysis of materials (e.g. food, packaging, app, dishwasher), competences (such as knowledge on how to order on-line food, where to return reusable trays) and meanings (convenience related to take away food, time saving, social gathering). From the LCA point of view, the goal and scope need to be defined, in particular the functional unit, which in this case was defined as "one year of delivering 60 sushi trays every day in Copenhagen".

The second step includes the inventory analysis (from the LCA point of view) and the study of consumers' practices (from PT point of view). The latter was done throught participant

observations in restaurants and the development of scenario-based workshops using design games. In these workshops consumers had to imagine a situation of consuming take away sushi both from a single-use plastic packaging and a reusable tray. This helped to identify an average return frequency of the reusable tray (equal to 15 days) and a return rate of the trays (equal to 90%) and these key parameters were used for the LCI.

In the third step from the PT perspective the empirical findings have been related to the PT triangle, i.e. materials, meanings, and competences, for both the current practice of doing takeway (i.e. via single-use packaging) and the new practice via a reusable sushi tray. In the fourth step the PT analysis previously developed has been integrated with the analysis of an existing practice in the Danish context, i.e. the return of beverage packaging via a deposit and return system. This comparison allowed to outline key elements for the successful implementation of the new practice, i.e. convenience in terms of access to a considerable number of return places and knowledge of where such return stations are. The third and fourth phase of the LCA (Life Cycle Impact Assessment, LCIA and life cycle interpretation) have been performed to draw conclusion for the comparative LCA.

The findings from both the PT and LCA analyses have finally be combined in a series of socio-technical recommendations for the decision makers involved in setting up the new system, i.e. the reusable sushi trays. In this way the combined PT-LCA analysis allowed to focus on the actions needed to be introduced in the system in a life cycle management perspective. The main advantage of the combined PT-LCA approach is to get access to information about the modelling of the use phase that are based on actual experiences from users and that can be easily implemented in the LCA modelling, to provide more real scenarios and reduce the number of assumptions in the modelling of the use phase.

3 Challenge n.2: improve communication of LCA results

This section outlines the challenges that are linked with the communication of LCA results (section 3.1) and discusses 4 approaches to make LCA results more understandable to a broader audience (section 3.2).

3.1 Issues with communication of LCA results

As stated in the Code of Practice (SETAC, 1999, p.41), "*presentation and communication are a vital element of any LCA. Without effective communication to decision-makers, LCAs will not contribute to improving environmental performance*". But at the same time it is acknowledged that "*external studies also face a fundamental challenge of balancing the amount of detail in order to describe accurately the LCA information and assumptions, while providing information in a form and language that meets the needs of the target audience* (p.37)." Nowadays, i.e. 30 years later, finding a balance between completeness and easiness of understanding of LCA results still remains a challenge.

Moreover, again quoting the Code of Practice: "*the needs of different audiences should be recognized and addressed when presenting or disseminating the study. Target audiences can be internal or external to the sponsoring organization. These audiences can include companies, trade associations, government agencies, environmental groups, scientific/technical communities, and other nongovernment organizations (e.g., consumers). Communication in the public domain is especially critical because the risks of misinterpretation are heightened when LCA-derived information is provided to audiences not familiar with complexity of the methodology"* (SETAC, 1993, p.41). It has been shown that consumers base their perception about the environmental sustainability of packaging on material types and disposal options (Boesen et al. 2019), so considering the properties of the packaging itself and the possible waste management options available, which means considering aspects that are outside of their direct influence.

There are also studies showing that consumers´ knowledge of environmental labels is limited, e.g. in the case of food packaging (Boesen et al., 2019; Nemat et al., 2019). Packaging counts in purchasing decisions as information is the means by which consumers search for consistency between personal attitudes and circular attributes of packaging (Testa et al. 2020). This means that there is a need to "educate" consumers on the meaning of different environmental labels and environmental claims or "green claims", which refer that a product or a service has environmental benefits or is less damaging to the environment than competing ones (EU Commission, 2016). However, given the role of green claims in guiding the market towards more sustainable options, it is key to understand whether consumers can distinguish claims that imply a different degree of companies' environmental commitment and therefore show a greater intention to buy those products with claims that require higher effort. This investigation has been recently done by Iovino et al. (2023), who, among other things, analyzed whether consumers recognise the value of a product whose environmental footprint has been calculated using a standardised institutional methodology such as Product Environmental Footprint (PEF). Their study show that the presence of a reference to the use of an institutional methodology has no effect on the attribution of the company's environmental commitment. In other words, it proved that it is not enough to provide consumers with certain amount of environmental information, but this information also need to be correctly conceived, received, and decoded, thus suggesting that consumer awareness on specific terms and claims needs to be increased, clarifying the different companies' commitments behind the claims.

3.2 How to make LCA results more understandable to a broader audience?

Presenting LCA results to consumers is not a straightforward task. On one side, there is too many information to be communicated, e.g. the results of more than 15 different impact categories. On the other side, if we consider a case of a comparative LCA, there is a simple question to be answered, i.e. is product A better than product B from an environmental point of view? So far, different options have been presented in literature to solve this dilemma that take different approaches.

One approach is the one introduced during the development of the Product Environmental Footprint Category Rules (PEFCR), i.e. to focus on presenting the most relevant impact categories for a specific product category and considering a representative product as a benchmark. The representative product is the average product sold in the EU market that is representative for the considered product group and it can be a real or a virtual product, i.e. non-existing product calculated based on weighted average of sales in the European market and taking into consideration all the existing technologies covered by the product category. The environmental performance of the representative product represents the benchmark, to which regards the environmental performance of other products can be compared (EC-JRC, 2021).

A second approach consists in the use of proxy indicators, i.e. using one or more LCIA indicators, such as Carbon Footprint (Laurent et al. 2012) or the Cumulative Energy Demand (Scipioni el al. 2013) as representative of other life cycle impact categories. This strategy can be adopted only in the cases in which there are correlations between impact categories, but it can be an effective way to reduce the amount of information that needs to be communicated to the consumers.

A third approach consists in using single scores, i.e. LCIA results calculated after the optional steps of normalization and weighting. As recommended by Pizzol et al. (2017) the choice of any normalisation references and weighting methods applied should be justified and documented, as required by the ISO standards on LCA. Furthermore, they recommend to communicate clearly the normalised results and weighted scores by, e.g. reporting units and explaining their meaning, as these may not be easily understandable to audiences beyond LCA experts. Finally they also point out the importance of clearly interpret results referring to the purposes and limitations of

the chosen normalisation and weighting approaches and to make sure that the decision makers are aware of the uncertainties and potential biases related to the use of normalisation and weighting.

A fourth approach consists in using values converted to popular references, such as the contribution to climate change translated into the km driven by a car. The effectiveness of this strategy has been tested in an online experiment by Vizzoto et al. (2021) who asked participants to rank the impacts of six 3-dimensional (water consumption, non-renewable energy use and CO_2 emissions) environmental profiles of coffee. With a 3 × 3 between-subjects design, they analyzed the answer accuracy under three communication styles (LCA standard units, values converted to popular references, and standardized units). They concluded that simplification does not always translate into better comprehension, as LCA data outperformed simplified communication styles in terms of consumer comprehension.

All of these strategies can be more or less effective in communicating LCA results, but a "translation" process needs to take place and further investigation is recommended in order to understand which is the best option under specific conditions.

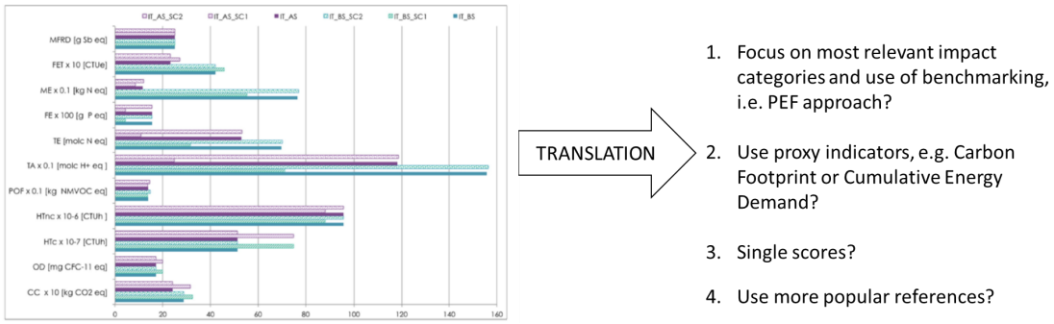

Figure 2. Illustration of the different approaches to perform the "translation" of LCA results.

4 Conclusions

To exploit the full potential of LCA as a decision support tool in the transition towards CE there is a need to address some unresolved issues. In this article we investigated two of the open challenges that in our view deserve primary attention.

The first one relates to the issue of getting a better understanding of consumers' practices: our proposal is to further investigate the combination of LCA with sociological approaches, such as Practice Theory. We presented a framework that allows to conduct a combined LCA-PT analysis and tested its applicability in the case of take away consumption, specifically a comparison between single-use vs reusable sushi tray, which showed that it is useful to conduct both analysis in parallel in order to provide more solid elements in the interpretation phase.

The second open challenge regards the need to deeply understand which are the mechanisms that favour or contrast a correct understanding of LCA results. In other words it is important to investigate drivers and barriers of the "translation" process that is needed to make sure that the results of an LCA study are clearly communicated to the broader audience beyond LCA practitioners. Our suggestion is to test the effectiveness of different stretegies already implemented (use of benchmark, proxy indicators, single scores and use of popular references) to understand which strategies are more suited according to a specific context and target audience.

Only when these crucial aspects will be addressed it will be possible for LCA to confirm its primary role as a tool able to provide decision-makers with information defining the environmental implications of the activities under analysis and identifying opportunities for true environmental improvements towards a CE transition, in line with the original intention outlined in the Code of Practice.

5 References

Bocken, NMP, Bakker, C, de Pauw, I. (2016) Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 2016, 1015, 20

Boesen, S, Bey, N, Niero, M (2019) Environmental sustainability of liquid food packaging: Is there a gap between Danish consumers' perception and learnings from life cycle assessment? J Clean Prod 210, 1193-1206.

Brändström, J, Saidani, M (2022) Comparison between circularity metrics and LCA: A case study on circular economy strategies. J Clean Prod 371 (133537)

Camacho-Otero, J, Boks, C, Pettersen, IN (2018) Consumption in the circular economy: A literature review. Sustainability (Switzerland) 10(8), 2758.

Danish Consumer Ombudsman (2021) Quick Guide on environmental claims. Available at https://www.forbrugerombudsmanden.dk/media/56743/quick-guide-on-environmental-claims.pdf

EC-JRC (2021) Understanding Product Environmental Footprint and Organisation Environmental Footprint methods. European Commission, Joint Research Center.

EU Commission (2016) Commission staff working document guidance on the implementation/application of directive 2005/29/EC on unfair commercial practices. SWD/2016/0163 final

EU Commission (2020). Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions A new Circular Economy Action Plan For a cleaner and more competitive Europe EN. In European Commission

Farrant, L, Olsen ,SI, Wangel, A (2010) Environmental benefits from reusing clothes. Int J Life Cycle Assess 15:726–736

Hunt, RG, William, EF (1996) LCA—how it came about—personal reflections on the origin and the development of LCA in the USA. Int J Life Cycle Assess 1(1):4–7

Iovino, R, Testa F, Iraldo, F (2023) Do Consumers Understand What Different Green Claims Actually Mean? An Experimental Approach in Italy, Journal of Advertising, DOI: 10.1080/00913367.2023.2175279

Konietzko, J, Bocken, N, Hultink, EJ (2020) A Tool to Analyze, Ideate and Develop Circular Innovation Ecosystems. Sustainability 12(1), 417

Laurent, A, Bakas, I, Clavreul, J, Bernstad, A, Niero, M, Gentil, E, Hauschild, MZ, & Christensen, T H (2014). Review of LCA studies of solid waste management systems--part I: lessons learned and perspectives. Waste Manage 34(3), 573–588.

Laurent, A, Olsen, SI, Hauschild, MZ (2012) Limitations of Carbon Footprint as Indicator of Environmental Sustainability. Environ. Sci. Technol. 46(7):4100-8

Leipold S., Petit-Boix A., Luo A., Helander H., Simoens M., Ashton W.S., Babbitt C.W., Bala A., Bening C.R., Birkved M., Blomsma F., Boks C., Boldrin A., Deutz P., Domenech T., Ferronato N., Gallego-Schmid A., Giurco D., Hobson K., Husgafvel R., Isenhour C., Kriipsalu M., Masi D., Mendoza J.M.F., Milios L., Niero M., Pant D., Parajuly K., Pauliuk S., Pieroni M.P.P., Luth Richter J., Saidani M., Smol M, Talens Peiró L., van Ewijk S., Vermeulen WJ, Wiedenhofer D., Xue B. (2023) Lessons, narratives and research directions for a sustainable circular economy. Journal of Industrial Ecology 27 (1), 6-18

Nemat, B, Razzaghi, M, Bolton, K, Rousta, K (2019) The role of food packaging design in consumer recycling behavior-a literature review. Sustainability 11(16), 4350.

Niero, M, Jensen, CL, Fratini, CF, Dorland, J, Jørgensen, MS, Georg S (2021) Is life cycle assessment enough to address unintended side effects from Circular Economy initiatives? J Ind Ecol 25(5),1111-1120

Niero, M, Olsen, SI (2016) Circular economy: to be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements. Resour Conserv Recyc 114: 18-31

Peña, C, Civit, B, Gallego-Schmid, A, Druckman, A, Caldeira- Pires, A, Weidema, B, Mieras, E, Wang, F, Fava, J, Milà i Canals, L, Cordella, M, Arbuckle, P, Valdivia, S, Fallaha, S, Motta, W (2021) Using life cycle assessment to achieve a circular economynt. Int J LCA 26:215–220

Pizzol, M, Laurent, A, Sala, S, Weidema, B, Verones, F, Koffler, C (2017) Normalisation and weighting in life cycle assessment: quo vadis? Int. J. Life Cycle Assess. 22, 853-866.

Polizzi di Sorrentino, E, Woelbert, E, Sala, S (2016) Consumers and their behavior: state of the art in behavioral science supporting use phase modeling in LCA and ecodesign. Int J Life Cycle Assess 21, 237–251.

Rabiu, MK, Jaeger-Erben, M, (2022). Appropriation and routinisation of circular consumer practices: A review of current knowledge in the circular economy literature. Clean Respons Consum 7. 100081

Rigamonti, L, Mancini, E (2021) Life cycle assessment and circularity indicators. Int J Life Cycle Assess 26:1937–1942

Roos Lindgreen, E, Mondello, G, Salomone, R, Lanuzza, F, Saija, G (2021) Exploring the effectiveness of grey literature indicators and life cycle assessment in assessing circular economy at the micro level: a comparative analysis. Int J Life Cycle Assess 26:2171–2191.

Sala, S, Amadei, AM, Beylot, A, Ardente, F (2021) The evolution of life cycle assessment in European policies over three decades. Int J Life Cycle Assess 26:2295–2314

Sazdovski, I, Bala, A, Fullana-i-Palmer, P, (2021) Linking LCA literature with circular economy value creation: A review on beverage packaging. Sci Total Environ. 771: 145322

Scipioni, A, Niero, M, Mazzi, A, Manzardo, A, Piubello, S (2013) Significance of the use of non-renewable fossil CED as proxy indicator for screening LCA in the beverage packaging sector. Int J of Life Cycle Assess, 18, 673–682

Schmidt-Rivera, X, Balcombe, P, Niero, M (2021) Chapter 3: Life cycle assessment as a metric for circular economy. In: Borrion A., Black M. Mwabonje O. (eds): 'Life Cycle Assessment: A Metric for The Circular Economy'. The Royal Society of Chemistry pp.54-80. Print ISBN:978-1-78801-445-8, PDF ISBN:978-1-78801-620-9

Schulte, A, Maga, D, Thonemann, N (2021). Combining life cycle assessment and circularity assessment to analyze environmental impacts of the medical remanufacturing of electrophysiology catheters. Sustainability, 13(2),1–23.

Schulz-Moenninghoff, Bey N, Nørregaard, PU, Niero, M (2021) Integration of energy flow modelling in life cycle assessment of electric vehicle battery repurposing: Evaluation of multi-use cases and comparison of circular business models. Resour Conserv Recyc 174, 105773.

Shevchenko, T, Saidani, M, Ranjbari, M, Kronenberg, J, Danko, Y, Laitala, K (2023) Consumer behavior in the circular economy: Developing a product-centric framework. J Clean Prod 384, 135568.

Shove, E, Pantzar, M, Watson, M, (2012) The Dynamics of Social Practice: Everyday Life and how it Changes. Sage, Los Angeles.

Steenis, ND, van Herpen, E, van der Lans, IA, Ligthart, TN, van Trijp, HCM (2017) Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations. J Clean Prod 162, 286–298.

Suski, P, Speck, M, Liedtke, C, (2021) Promoting sustainable consumption with LCA – A social practice based perspective. J Clean Prod 283, 125234

SETAC (1993) Guidelines for Life-Cycle Assessment:A "Code of Practice". Edition 1. From the SETAC Workshop held at Sesimbra, Portugal 31 March - 3 April 1993. Society of Environmental Toxicology and Chemistry

Testa, F, di Iorio, V, Cerri, J, Pretner, G, (2021) Five shades of plastic in food: Which potentially circular packaging solutions are Italian consumers more sensitive to. Resour Conserv Recycl 173.

Testa, F, Iovino, R, Iraldo, F (2020) The circular economy and consumer behaviour: The mediating role of information seeking in buying circular packaging. Bus. Strategy Environ. 2020, 29, 3435–3448.

Truong, PH. Nicot, FE, (2022) Reusable packaging solution for takeaway. A practice-oriented study for Life Cycle Assessments. M.Sc. Sustainable Design Engineering. Master thesis project. Aalborg University. Copenhagen.

UNEP (2021). Addressing Single-use Plastic Products Pollution Using a Life Cycle Approach. United Nations Environment Programme. Nairobi.

Vizzoto, F, Testa, F, Iraldo, F (2021) Towards a sustainability facts panel? Life Cycle Assessment data outperforms simplified communication styles in terms of consumer comprehension J Clean Prod 323: 129124