Combining Life Cycle Assessment and Practice Theory to understand the influence of consumers´ practices on food waste sorting

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Abstract: This study aims to investigate how Practice Theory (PT) can support Life Cycle Assessment (LCA) in developing strategies to reduce the environmental impacts associated with the practice of food waste sorting. A case study on the Danish island of Bornholm is considered, where a new food waste sorting system for households is going to be introduced. The insights given by PT in terms of materials and competences needed to perform the practice as well as the meaning associated by consumers to food waste sorting allowed to identify which actions decision makers should prioritize in order to increase the food waste sorting fraction.

1. Introduction

1.1 Life cycle assessment of food waste sorting in a circular economy

A key principle of the Circular Economy (CE) is to eliminate the concept of waste and always keep products and materials at their highest utility and value (EMF, 2013). In the CE, waste is considered as a resource, and it should therefore be kept in a closed loop. With reference to the well-known butterfly diagram of the EllenMacArthur Foundation (EMF, 2013), waste belong to the biological cycle when nutrients from biodegradable materials, such as food waste, are returned to Earth through methods like composting and anaerobic digestion. The EU CE Action Plan highlights the key role of waste sorting in the transition towards a CE: "*high quality recycling relies on effective separated collection of waste*" (EU Commission, 2020, p. 13).

Life Cycle Assessment (LCA) is a powerful tool that can be used to assess what is the preferred option for waste treatment and management from an environmental point of view. Based on a review of 222 LCA studies in the solid waste management systems field, Laurent et al. (2014) concluded that the strong dependence of each management system on its context or local specificities prevents a consistent generalization of LCA results. They recommend stakeholders in the field of solid waste management to consider LCA as a tool to determine "context-specific waste hierarchies", i.e. waste hierarchies that are adapted to local conditions, including consideration of site-specific waste composition, treatment efficiencies, local energy mix, etc., and thus not necessarily identical to the generic waste hierarchy.

The main focus of organic waste LCAs (which includes food waste) so far has been on the technological waste treatment solutions, e.g. Andersen et al. (2012). Other aspects investigated by organic waste LCAs are management strategies when biologically treating source-sorted organic household waste (Khoshnevisan et al., 2018) or food waste and biogas digestate

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management options (Xiao et al., 2022). To our knowledge, only one LCA study was performed on "food waste sorting", i.e. Bernstad et al. (2011) who compared a real scenario for waste sorting in households including food waste with an ideal sorting scenario in a case study from Sweden. They concluded that an improved source sorting behavior in the household would result in a better environmental impact and higher quality of the recovered products. They relied on assumptions about certain amounts of source sorted waste being sent for treatment, thus revealing a lack of focus on the actual source sorting at household level. However, source sorting represents a key factor to be investigated that decision makers in the waste management sector should not neglect.

Rousta et al. (2017) argue that there is a need for multidisciplinary research within the field of waste sorting behavior and material recovery from municipal waste. They identified some key factors that mainly affect recycling behavior: appropriate physical infrastructure, shorter distance to collection points, reliable service, user convenience and adequate information. The better the households are at sorting, the cleaner the material composition of the waste fraction are, and, in the end, the recovered product will be of a higher quality. Katan & Gram-Hanssen (2021) performed a case study on waste sorting in households in Denmark and investigated how social norms can interfere with the practice of waste sorting. They identified different social norms that make people deviate from their normal waste sorting practices, e.g. when there are guests or bigger social events the sorting practice is often obstructed because the guests do not know the 'sorting rules' or it feels impolite for the host to be the 'guardian of moral rectitude'.

1.2 A case study of food waste sorting on an island

In this paper, a case study on the Danish island of Bornholm, located in the Baltic sea, is considered. Denmark ranks as the leading country in Europe in terms of municipal solid waste generation per capita: in 2020 the average Danish household indeed generated 845 kg of waste per person, compared to 505 kg of the average European household (Eurostat, 2021). Moreover, in 2019 only 42% of the waste from households in Denmark were sent for some sort of material recycling (Miljøministeriet, 2021). To comply with the European targets for source sorting of municipal waste, by July 1st 2021, all Danish municipalities were obliged to establish collection schemes for source sorting household waste in several fractions: food, paper, cardboard, metal, glass, plastic, cartons from food and beverage and dangerous waste. The purpose of aligning the waste management systems across all municipalities was to increase the potential of recycling waste and to reduce confusion about how to sort among citizens. However, due to challenges of establishing the infrastructure for the collection schemes, 74 out of 98 municipalities, including Bornholm, got dispensation to postpone the establishment of collection schemes until December 31st 2022 (Miljøministeriet, 2021). In the beginning of 2022 very few types of waste were source sorted on the island: paper, cardboard and textile were collected in one bin and residual waste in another bin at the households on Bornholm. In the new waste handling system the households will be required to sort in 12 different fractions via four different containers: residual waste and plastic/food and drinking carton in one container, food waste in a second one, carboard and paper, and glass and metal in a third one and finally hazardous waste in the fourth container. Limited physical space is one of the common difficulties that islands face in setting up and operating conventional waste management systems. Other challenges are linked to high operational costs; small market sizes and diseconomies of scale, and changing social norms regarding product reuse, repair, and recycling (Eckelman et al., 2014). This makes the case of setting a new sorting system in an island particularly challenging and interesting at the same time.

1.3 Aim of the study

There are limitations to what LCA can adequately grasp with the existing methodology and this affects how much decision makers can rely on the LCA results for decision support in waste management. Given such limitations of LCA as a decision support tool, previous studies suggest to combine it with other methods from other research fields, such as behavioral science (Polizzi

di Sorrentino et al., 2016) or sociological approaches, such as Practice Theory (PT) (Niero et al., 2021; Suski et al., 2021). In particular, Niero et al (2021) propose that one strategy to extend the potential of LCA in supporting decision-making is to complement LCA with PT, which consider societal dynamics as socio-technical and focus on the practices through which production and consumption dynamics change. Based on the premises of Niero et al (2021), this study aims to answer the following research question: **How can Practice Theory support decision making in reducing the environmental impacts associated with the practice of food waste sorting?** A case study on the island of Bornholm is used to illustrate what a combination of PT and LCA can add to the assessment of a new sorting system for the food waste fraction.

2. Materials and methods

The analysis was performed by means of practice theory (PT) as analytical lens using ethnographic methods to collect data (section 2.1) and LCA as a main quantitative method (section 2.2). The approach followed is reported in Figure 1, combining the sociotechnical approach (PT) and the quantitative environmental sustainability method (LCA) to provide suggestions for improving the decision-making process.

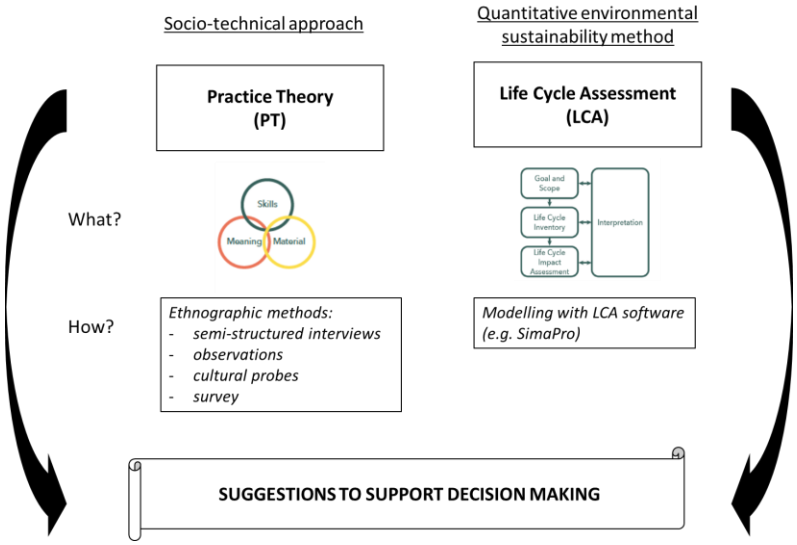

Figure 1. Illustration of the combined socio-techncial and quantitative environmental sustainability assessmemt approach to provide suggestions for the decision making process, consisting of the application of Practice Theory (PT) and Life Cycle Assessment (LCA).

2.1 Practice Theory (PT)

PT was applied in order to understand what it takes for inhabitants on Bornholm to start source sorting their food waste, therefore source sorting of food waste is recognized as a practice, in accordance with Katan & Gram-Hanssen (2021). There is no univocal definition of what a practice is, but here the definition proposed by Shove and Pantzar (2005) is followed, where a practice is an active integration of materials, meanings and forms of competence. The materials refer to the physical objects or infrastructures required to perform the practice, e.g. a waste bin. The meanings are the reasoning why a practice is performed, e.g. to fulfill a requirement from the municipality or to reduce the personal environmental footprint. Finally, the competence includes the skills and knowledge needed to perform the practice, e.g. the knowledge on how to sort the different waste fractions (Pantzar and Shove, 2010; Shove and Pantzar, 2005).

The rationale behind the adoption of PT as a theoretical lens is that by understanding the three aspects of the practice (materials, meanings, and competences) and their interconnections, it is possible to gain valuable insights of what differentiates the current sorting practice from the future one. In order to investigate a not yet established practice in the future (source sorting of food waste in households on Bornholm) the concept of a proto-practice is adopted, meaning a practice not yet established with no clear interconnections of the elements which make up the practice (Pantzar and Shove, 2010, p. 5). We investigated what factors influence and can trigger the deformation of the current practice, but also what factors can help form or deform the future practice of sorting food waste. The main aim of doing the PT analysis of the current situation and the future situation was to answer the three following questions:

- What are people currently doing with their waste?
- Why do they do what they do?
- How can it be changed what people do?

Several ethnographic methods have been used to perform such PT analysis, namely semi-structured interviews, observations, cultural probes and survey. Semi-structed interviews were used to gain new knowledge from the respondents by asking them different questions, allowing them to affect the conversation. Observations were used to better understand if what people said they do is what they actually do. They were used during the interviews and where waste sorting was embedded in the situation, both inside and outside households and they were performed with little interaction besides a few questions in the performance of the observed situation. Main actors involved were part of a housing association on Bornholm (named Bo42 located in Rønne, i.e. the most densely populated centre on Bornholm).

Cultural probes are artefacts that can be used to ”provoke“ inspirational responses from research participants and can be materialised in many different ways e.g. notebooks, maps, camera, postcards with tasks or questions etc. Participants receive the probes and ”live with them” for a certain period of time, after which the probes are returned to the designers/researchers (Gaver et al., 1999). Cultural probes were used in the study to gain inspiration and insight into the challenges of sorting food waste from people who are not used to sort their food waste. A total of five different households were involved. The cultural probes consisted of a kit with a bucket, biodegradable bags (approx. 10 pieces), a notebook, a welcoming letter with instructions and some chocolate. Finally, a survey was created to obtain empirical knowledge from the field in a more quantitative way, to supplement the qualitative empirical gatherings done through interviews and cultural probes. It was addressed to the local citizens of Bornholm and was done for two main purposes: i) to use the knowledge gained from interviews and see if this was representative when looking at the larger population of Bornholm and ii) to identify potential barriers or issues that could arise when the local citizens of Bornholm have to start sorting their food waste. More detailed information on how the empirical knowledge was gathered is reported in Langstrup Hagerstrand et al. (2022, cfr. section 5).

2.2. Life Cycle Assessment of different source sorting scenarios

The software SimaPro version 9.3.0.3 was used to perform the LCA modelling and assess how source sorting of food waste in the households affects the total environmental performance of the food waste management systems on Bornholm. The food waste management system considered includes all processes from source sorting in the household, collection, transport, treatment and the benefits gained from recycling the waste. According to the waste management company, it is estimated that the households on Bornholm will generate appr. 3000 tons of source sorted food waste when they at the end of 2022 start to sort food waste (Bornholms Regionskommune, 2021). The comparative LCA study includes three scenarios: i) No Source Sorting (NSS), which reflects the way of treating food waste on Bornholm in 2022, i.e. 100% sent to incineration in a local incineration plant; ii) Low Source Sorting (LSS), where 33% of food waste is sent to anaerobic digestion and 67% to incineration and iii) High Source Sorting (HSS),

representing an optimal source-separation program with 80% sent to anaerobic digestion and 20% sent to incineration. The different sorting rates are estimated based on assumption provided by (Bernstad et al., 2011), who investigated a waste source separation program in Sweden.

The chosen functional unit is the "handling (including sorting in household, collection, transport, treatment and potential avoided burdens from end product) of 3000 tons of food waste from households on Bornholm." In terms of system boundaries, the zero burden assumption was considered, meaning that the upstream environmental impacts from production, transportation and use of the wasted products are not included (Astrup et al., 2018). In the present study this implies that the production and transportation of food is not included in the LCA modelling. The LCI modelling framework chosen is consequential, therefore multifunctional processes were handled using system expansion, meaning that the avoided impacts from the end product, respectively heat for the incineration plant, and electricity from biogas and fertilizer for digestate coming from the anaerobic digester were modelled as avoided marginal products. The system boundaries are represented in Figure 2.

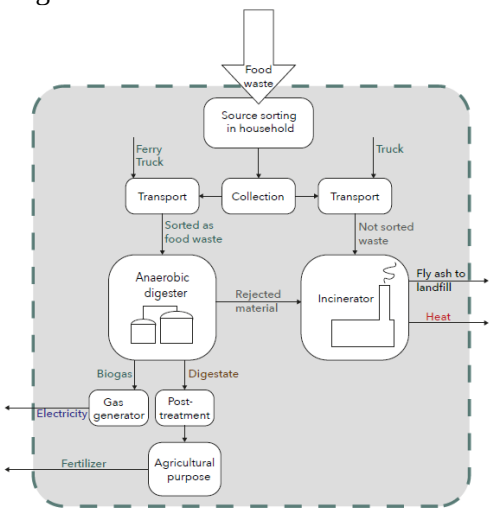

Figure 2. System boundaries of the comparative LCA study, considering the two main treatment options, i.e. anaerobic digestion and incineration with energy recovery. Source: Langstrup Hagerstrand et al. (2022).

The LCI modelling of the three different source sorting scenarios (HSS, LSS; NSS) was performed with the ecoinvent 3.8 – consequential database.

The life cycle impact assessment (LCIA) was performed using the Environmental Footprint 3.0 (EF 3.0) methodology (Fazio et al., 2018), as embedded in SimaPro v9.3.0.3. Apart from the characterization step, also the two optional steps of normalization and weighting were performed in order to get to a single score and be able to directly compare the three scenarios.

As part of the life cycle interpretation, two different sensitivity analysis were performed to respectively identify: i) the critical amount of food waste to be sourced sorted to reach a breakeven compared to no sorting and to test ii) if it matters whether the treatment facility is located on Bornholm or if the waste is transported to the closest Danish facility.

3. Results and discussion

From the results of the comparative LCA represented in Figure 3 it can be concluded that the higher amount of food waste sorted and send for biological treatment the better environmental footprint. This applies if at least 5% of the 3000 tons of food waste are send for biological treatment in a scenario where the substituted product to produce heat is biomass – as is the case on Bornholm under normal circumstances.

From the sensitivity analysis, it can be concluded that the determining factor for the results is the choice of substituted products. The location of the treatment facilities does have an impact when looking at the emissions from managing the food waste. Local treatment, reducing the amount of needed transport, is initially prefered, but should be further investigated before any final conclusions can be made. The benefits from recycling the waste seem to overrule the impacts from the treatment and transport processes. The LCA results can be used for decision support to argue for investing in efforts that can help the households to increase sorting of food waste – and supposedly also other waste fractions. But it should be kept in mind that the biggest environmental benefits would come from generating no food waste at all.

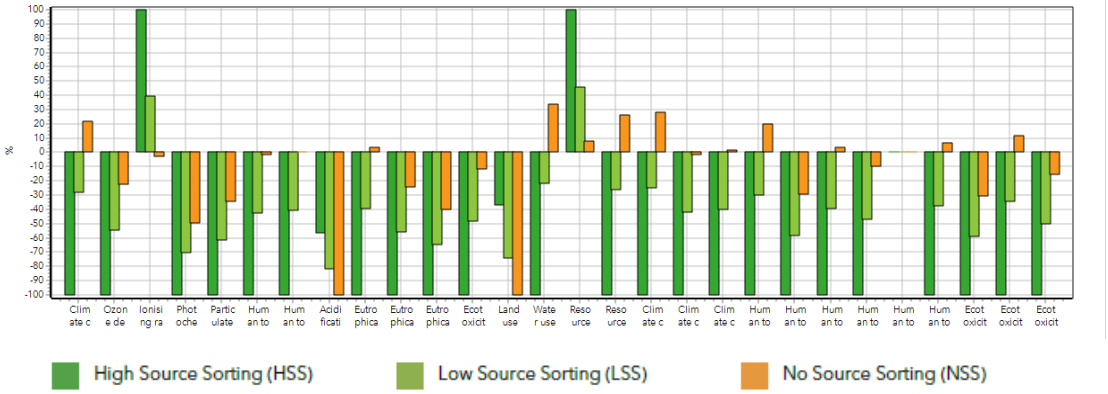

Figure 3. Characterized LCIA results considering the three cases: High Source Sorting (HSS, 80% sent to anaerobic digestion (AD) and 20% to incineration) vs Low Source Sorting (LSS, i.e. 67% senti to AD and 33% to incineration) and No Source Sorting (NSS, i.e. 100% sent to incineration).

Once understood from the results of the comparative LCA that sorting does matter on the overall environmental performances of the food waste management system, it was essential to better understand the actual practice of sorting food waste. Thus, the PT analysis looked at the meanings, skills and materials that together comprise the "practice of getting rid of waste" from households, mainly apartments, in the housing association Bo42 in Rønne, as summarized in Figure 4a. It can be argued that most findings are also representative of people living elsewhere on the island, but we acknowledge that the practice will differ depending on what type of housing people live in. Key elements in the analysis of the current practice relate to the following:

- Meanings: "easiness" to get rid of the waste, due to short distance with the waste bin and reduced amount of waste bins in the kitchen; need to keep waste hidden as their value as resources is not recognized and finally "obedience" to what authorities says;
- Skills: knowledge on how to sort correctly the different fraction, how to store (in which container), when waste should be deposited in the container (affecting the smell and possibility of leaking if food waste stays for too long in the bin);
- Materials: including waste itself, the waste bin used to store the food waste, bag, container for final collection of the waste fraction, labels describing the type of waste that needs to be put in the container for final collection (sometimes missing).

From the analysis it emerged that the current practice of getting rid of waste is deforming, due to changes in meanings and soon materials, when the new sorting system is implemented. There are elements that support the forming of the new food waste sorting practice, such as the willingness to sort, easiness during the experiment, since citizens were provided with a bin, bags, guidelines for what can be sorted as food waste and clear instructions; knowledge on what can be sorted as food waste and what type of bag can be used for sorting food waste, but also what kind of bag is most resistant to leakages. Finally the importance of the waste bucket (linked to waste being "invisible") and provision of clear guidelines to follow should be outlined.

There are also elements that deform the practice, i.e. prevent the practice from being established, such as too long distance to the collection container, the feeling of "not being a policeman" when guests are at home, the expectation to receive a full solution from the waste management company and finally the reluctance to change habits. An overview of the main aspects to be considered by the decision makers is represented in Figure 4b.

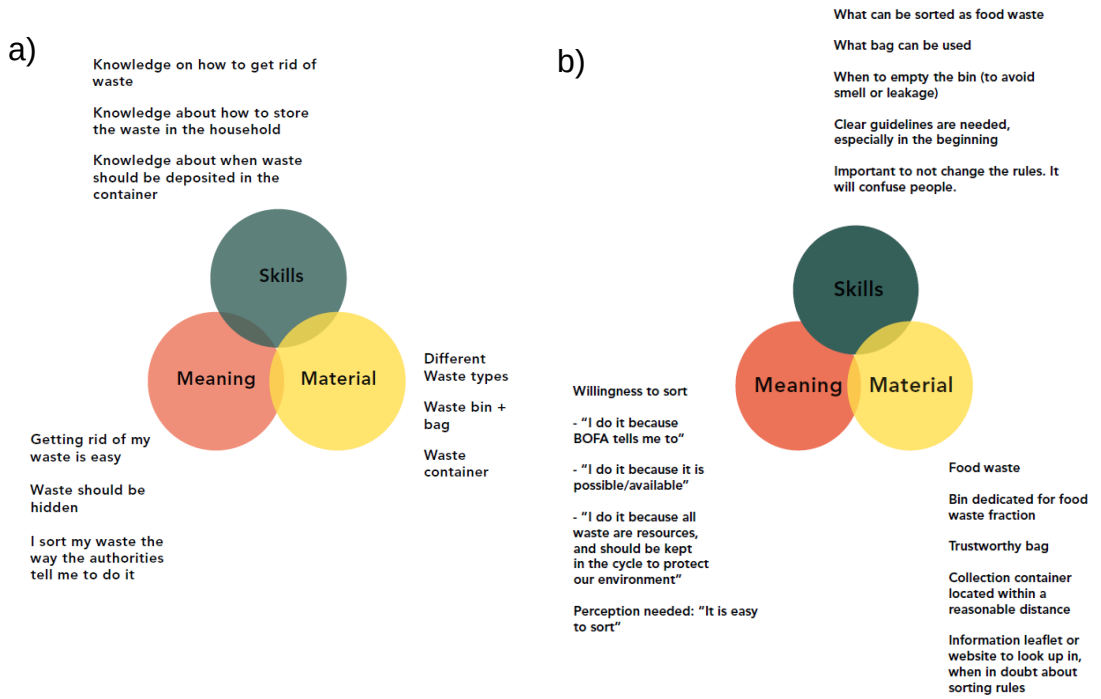

Figure 4. Practice Theory (PT) analysis of a) current practice of "getting rid of food waste" and b) "proto-practice", i.e. a new practice in the making, including the meanings, materials and skills needed to perform the practice.

4. Conclusions

By combining PT and LCA in an empirical case study, this study shows how the practice of 'sorting food waste' can be established, but also what barriers might come in the way and what the environmental benefits from recycling food waste are. A final set of recommendations to the local decision makers (i.e. the waste management company on the island) have been given about how they can support the households to sort food waste. It was found that from an environmental perspective it does matter to sort food waste and send it to biological treatment, even if it must be transported away from the island to do so. Furthermore, the results showed that information about what can be sorted as food waste, households' willingness to sort and the right equipment (bin, bag, containers), are amongst the vital elements to establish the practice to reach a high sorting rate. These findings can be considered when using LCA as a decision support tool, e.g. through the focus on elements that are relevant for the LCA results, such as the bag (e.g. Dolci et al. 2021) and when different scenarios are considered. This can give relevance to the role that consumers play when performing different practices and suggest developing further the role that PT can play when performing LCA, as already suggested by Suski et al. (2021).

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